# SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

## *Special Features*

Activated Sludge Fundamentals—McKinney and Horwood

Filter Fly Control—Schaetzle

Ammonia Still Wastes—Mathews

Beet Sugar Wastes Guide—Black and McDermott

National Water Policy—Howson

FEBRUARY, 1952—VOL. 24, No. 2

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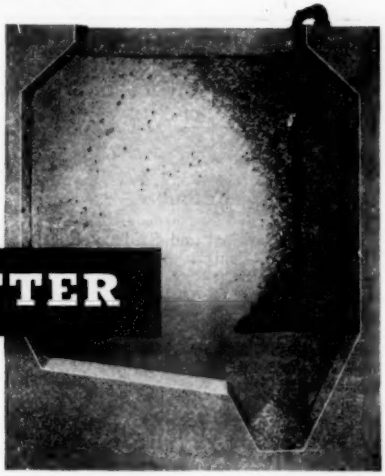
Please remit immediately upon receipt of the first dues notice from your Member Association Secretary.

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS
325 Illinois Bldg. Champaign, Ill.

# 6
## IMPORTANT BASIC FEATURES

## *Chicago*
# AER-DEGRITTER



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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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# HOW TO MEASURE TRADE WASTES ACCURATELY

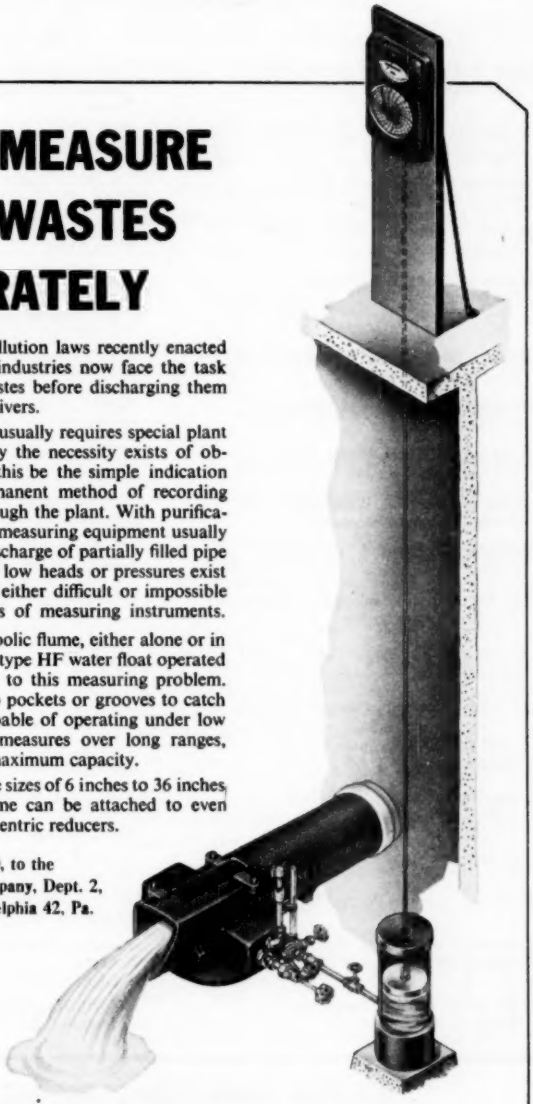
In accordance with anti-pollution laws recently enacted by numerous states, most industries now face the task of purifying their plant wastes before discharging them into adjacent streams and rivers.

This purification process usually requires special plant construction, and invariably the necessity exists of obtaining flow data, whether this be the simple indication of flow rate or a more permanent method of recording and totalizing the flow through the plant. With purification processes of this kind, measuring equipment usually is located at the point of discharge of partially filled pipe or in open channels, where low heads or pressures exist and where measurement is either difficult or impossible when using standard forms of measuring instruments.

The Simplex type S Parabolic flume, either alone or in conjunction with a Simplex type HF water float operated meter, is the ready answer to this measuring problem. Compact in design, with no pockets or grooves to catch sediment or solids, and capable of operating under low flow conditions, the unit measures over long ranges, from maximum to 5% of maximum capacity.

Available in standard pipe sizes of 6 inches to 36 inches diameter inclusive, the flume can be attached to even larger sizes by means of eccentric reducers.

**Write for Bulletin 210, to the Simplex Valve & Meter Company, Dept. 2, 6719 Upland Street, Philadelphia 42, Pa.**



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## MEMBER ASSOCIATION MEETINGS

| *Association* | *Place* | *Time* |
|---|---|---|
| Texas Water and Sewage Works Association | Texas A. & M., College Station, Texas | March 9–13, 1952 |
| New Jersey Sewage and Industrial Wastes Association | Hotel Traymore, Atlantic City, N. J. | March 12–14, 1952 |
| Louisiana Conference on Water Supply and Sewerage | La. State University, Baton Rouge, La. | March 19–21, 1952 |
| Arizona Sewage and Water Works Association | Maricopa Inn, Mesa, Ariz. | April 3–5, 1952 |
| Arkansas Water and Sewage Conference | Engineering Building, University of Arkansas, Fayetteville, Ark. | April 7–9, 1952 |
| Montana Sewage and Industrial Wastes Association | Northern Hotel, Billings, Mont. | April 10, 1952 |
| South Carolina Water and Sewage Works Association | Clemson College, Spartansburg, S. C. | April 10–12, 1952 |
| Maryland-Delaware Water and Sewerage Association | Wardman Park Hotel, Washington, D. C. | April 17–18, 1952 |
| Virginia Industrial Wastes and Sewage Works Association | Hotel Roanoke, Roanoke, Va. | May 12–13, 1952 |
| Michigan Sewage and Industrial Wastes Association | Park Place Hotel, Traverse City, Mich. | May 19–21, 1952 |
| Ohio Sewage and Industrial Wastes Treatment Conference | Commodore-Perry Hotel, Toledo, Ohio | May 21–23, 1952 |
| New England Sewage and Industrial Wastes Assn. | Hotel Elton, Waterbury, Conn. | May 22–23, 1952 |
| Alabama Water and Sewage Assoc. | Pitts Hotel, Auburn, Ala. | June 4–6, 1952 |
| Central States Sewage and Ind. Wastes Assn. | Loraine Hotel, Madison, Wisc. | June 25–27, 1952 |
| Pennsylvania Sewage and Ind. Wastes Association | Pennsylvania State College, State College, Pa. | Aug. 27–29, 1952 |
| Iowa Sewage Works Association | Grinnell College, Grinnell, Iowa | Sept. 9–11, 1952 |
| Rocky Mt. Sewage Works Assn. | Frontier Hotel, Cheyenne, Wyo. | Sept. 15, 1952 |
| Kentucky-Tennessee Industrial Wastes and Sewage Works Assn. | Andrew Johnson Hotel, Knoxville, Tenn. | Sept. 15–17, 1952 |
| South Dakota Water and Sewage Works Conference | Marvin-Hughitt Hotel, Huron, So. Dakota | Sept. 17–19, 1952 |

### SILVER ANNIVERSARY MEETING

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**in conjunction with**

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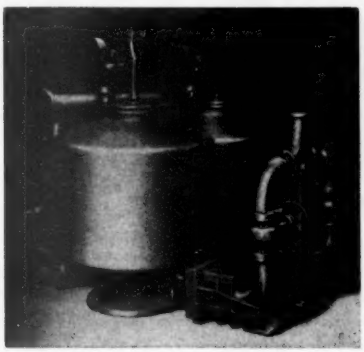

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1. Murdock, Harold R., Ind. and Eng. Chem., Vol. 43, November, 1951.

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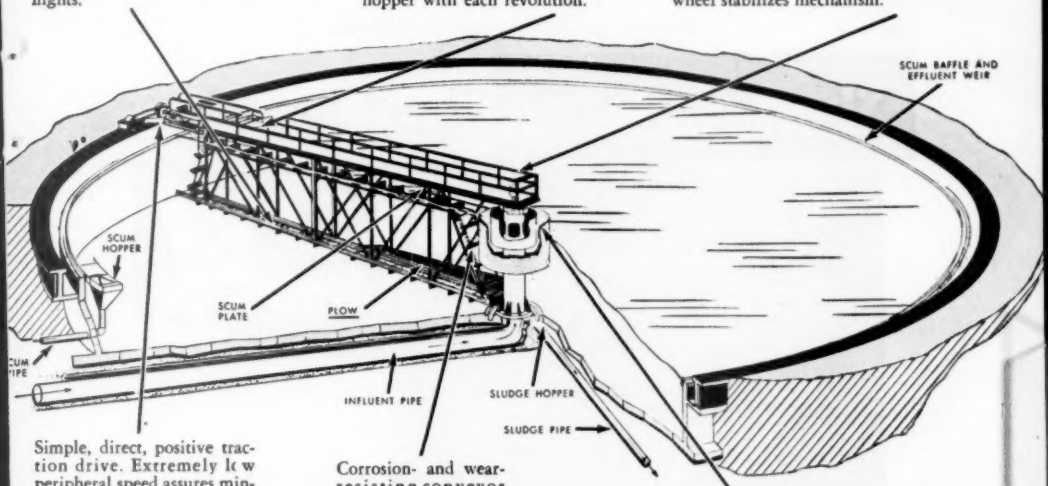


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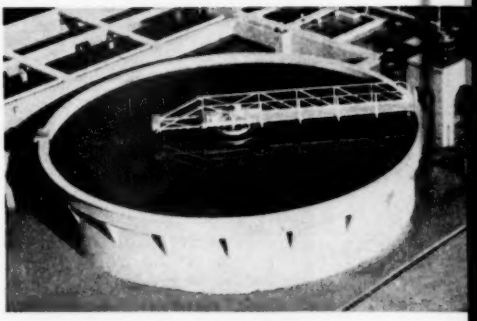

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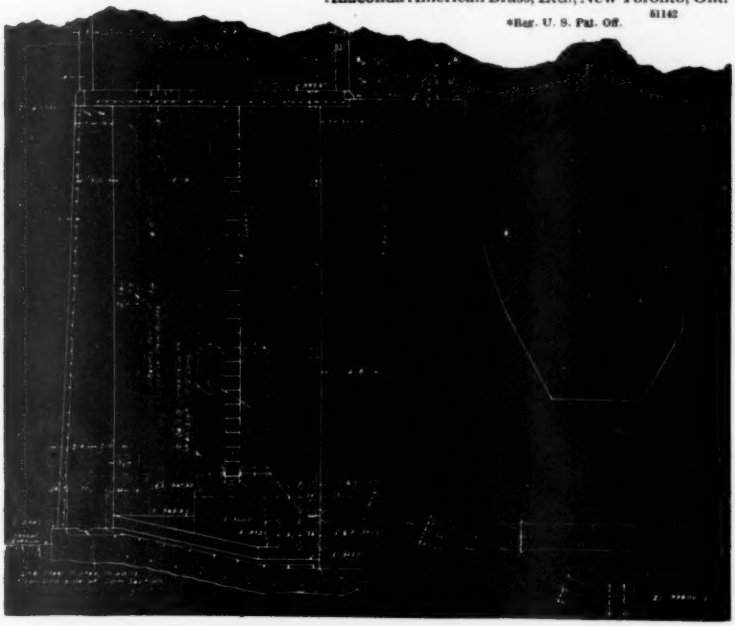

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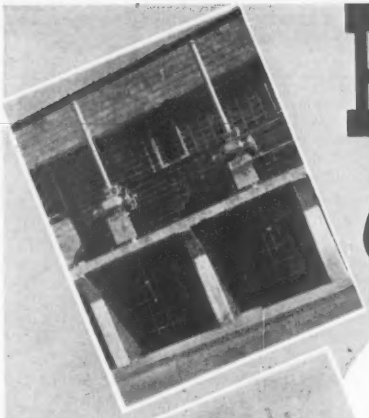

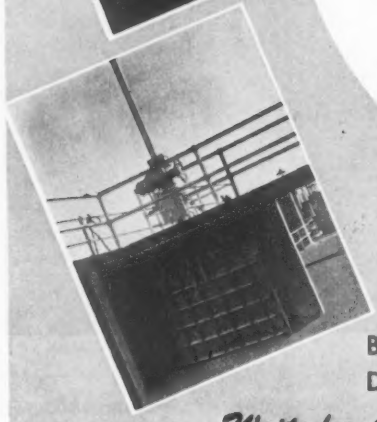

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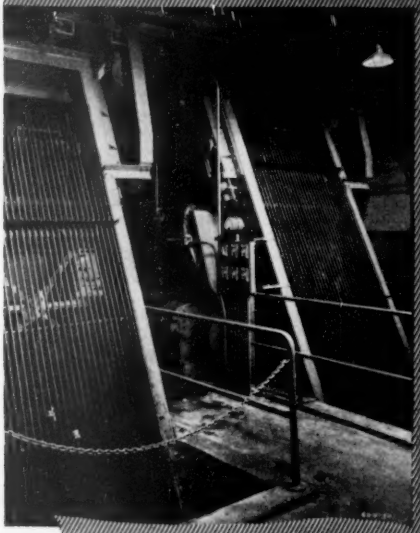

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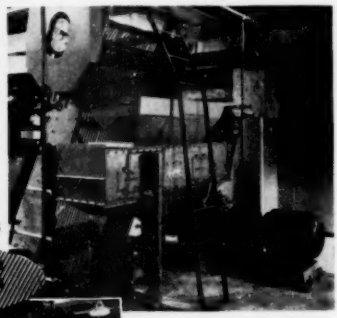

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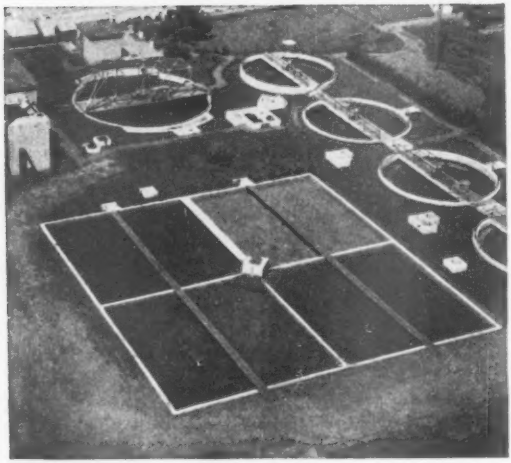

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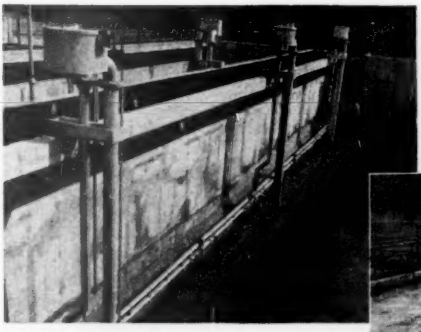
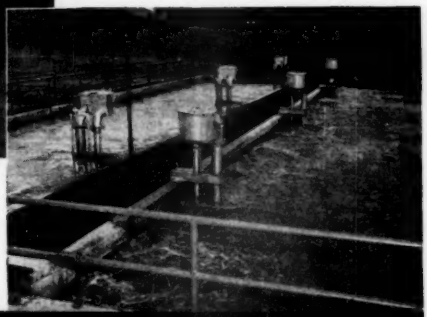


DIFFUSAIR installation at Kirkwood, Mo. Impingement nozzles and bowls are on headers at lower left side of tank.



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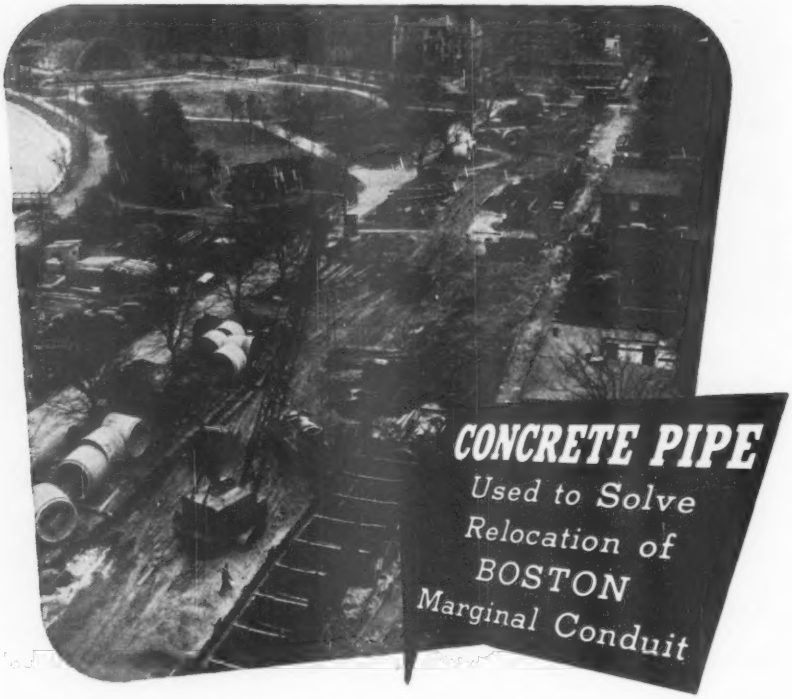


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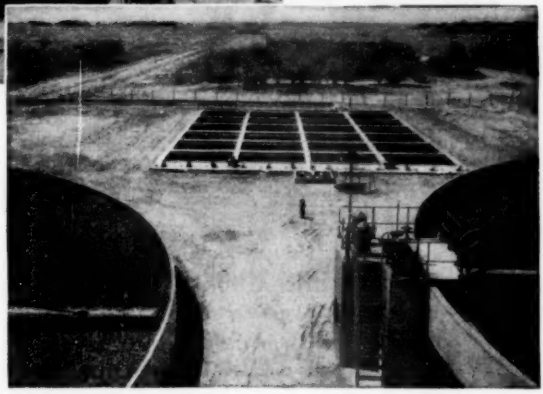

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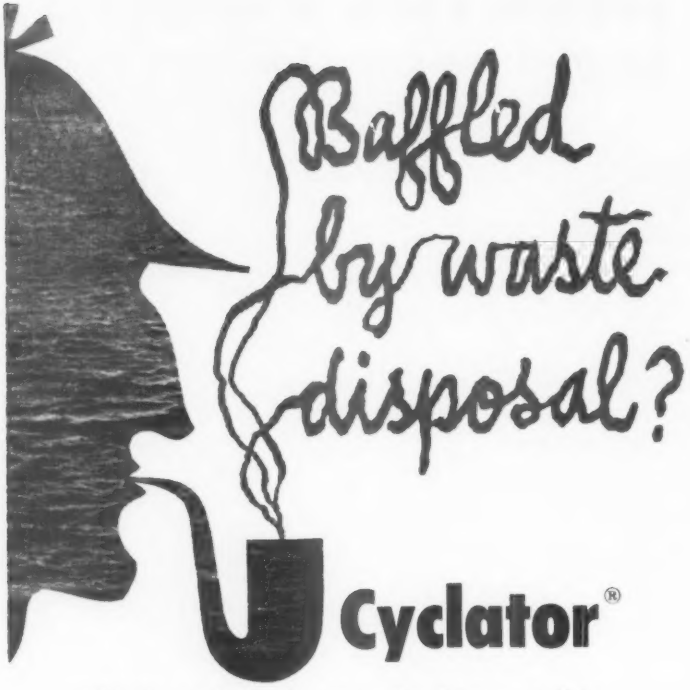


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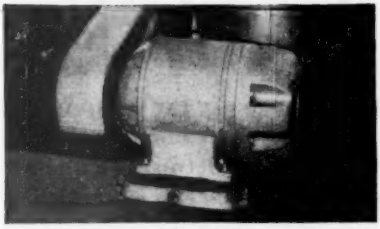

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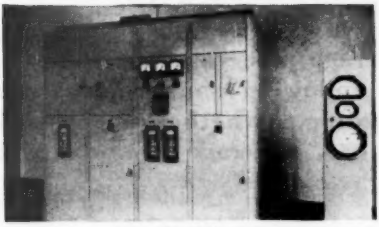

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# SEWAGE AND INDUSTRIAL WASTES

*Journal of the Federation of Sewage and Industrial Wastes Associations*

**Volume 24** **FEBRUARY, 1952** **Number 2**

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# Sewage Works

## FUNDAMENTAL APPROACH TO THE ACTIVATED SLUDGE PROCESS *

### I. Floc-Producing Bacteria

By Ross E. McKinney † and Murray P. Horwood

*Research Assistant and Professor of Sanitary Science, respectively, Sedgwick Laboratories of Sanitary Science, Massachusetts Institute of Technology, Cambridge, Mass.*

The widespread use of activated sludge for waste treatment has prompted considerable research on improving this process over the past quarter of a century. The majority of research has been directed towards the physical and chemical aspects of the process as a whole. Very little has actually been done to study the fundamental units of activated sludge, the bacteria, as such. It is the purpose of this paper to present information on some of the floc-producing bacteria found in activated sludge.

#### Previous Work

Butterfield (1) was the first to isolate an organism which formed a floc similar to activated sludge when aerated in a suitable substrate. This organism was identified as *Zooglea ramigera.*

The ability of *Z. ramigera* to oxidize organic substrates was studied quite extensively by research teams of the U. S. Public Health Service in Cincinnati (2)(3)(4)(5). Heukelekian and Littman (6)(7) also isolated the zoogleal organisms found in activated sludge. A review of the cultural characteristics of all of the organisms that they isolated showed that the bacteria were of the class *Z. ramigera,* as set forth by Butterfield (1).

Later, in 1941, Butterfield and Wattie (8) found that the zoogleal organisms active in the trickling filter were identical and interchangeable with the zoogleal organisms in activated sludge. Wattie (9) followed this work with extensive research on the cultural characteristics of a large number of zoogleal organisms isolated from both trickling filters and activated sludge. These bacteria were also classed as *Z. ramigera.*

Aside from the research of Butterfield, Heukelekian, and Wattie, very little work has been done concerning the bacteria in activated sludge. The rapid ability of *Z. ramigera* to stabilize nutrient substrates has caused it to be accepted as the primary organism in activated sludge and has resulted in an apparent lack of interest in the remaining bacteria.

#### Equipment and Procedure

Two procedures were used in the isolation of the floc-producing bacteria in this study—multiple transfer and direct aeration. The multiple transfer procedure was essentially the same as set forth by Butterfield (1) and modified by Wattie (9) and will not be repeated in this paper.

The direct aeration procedure was the result of an attempt to duplicate the aeration unit of the activated sludge process in miniature by means

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; St. Paul, Minn.; Oct. 8–11, 1951.

† Present address: Foundation of Applied Research, San Antonio, Tex.

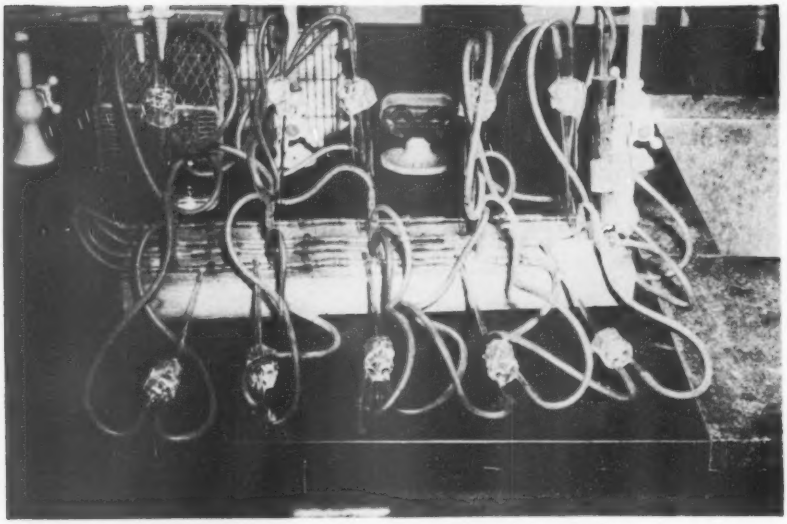

**FIGURE 1.—Aeration units used in isolation studies.**

of the apparatus shown in Figure 1. Each rack contained 11 22- by 175-mm. pyrex culture tubes arranged in two parallel rows of five tubes each. The extra tube was placed between the two parallel rows at one end of the rack and served as the wash tube. The wash tube was filled with water to wash the incoming air free of impurities and to resaturate the air with water vapor, thereby reducing evaporation losses. After the air had been washed, it was passed through a cotton filter to remove excess water vapor and impurities which passed through the wash water. The air went from the filter through the aeration units and a second filter and out into the atmosphere. The air inlet devices were arranged so that the aeration units were in parallel. This permitted uniform pressure to be supplied to the units and prevented carryover from one unit to another. The air outlets were also arranged in parallel. The final cotton filter prevented a backflow of contamination from the atmosphere when the air was off.

In the direct aeration procedure 1 ml. of concentrated activated sludge was added to 9 ml. of sterile dilution water in a sterile weighing bottle containing several glass beads. The sludge was shaken quite rapidly for 1 min. and then multiple dilutions were made into sterile dilution water. Transfers in the amount of 1 ml. were made from the dilution water into sterile 1/10 nutrient broth in the aeration units. Five dilutions were set up from each sample of sludge, with the normal range of dilutions from 1/1,000 to 1/10,000,000. After the inoculations were made, the units were aerated.

If a unit showed sludge formation within 24 hr., a sample from that aeration unit was streaked onto nutrient agar plates. These plates were incubated at 30° C. for 24 to 48 hr. Representative colonies of each type of growth were picked from the plates and placed into aeration units containing fresh substrate. If the organism showed sludge formation in the second unit, it was identified using the standard identification procedures as

set forth by the Society of American Bacteriologists. Stock cultures were made and set aside for later use.

If the aeration unit did not show sludge formation in 24 hr., it was aerated for several days until it became apparent that there was not going to be any sludge formed.

### Organisms Isolated

The use of both isolation procedures resulted in the isolation of 11 organisms, which were capable of forming a floc similar to activated sludge when aerated in a nutrient substrate. On the basis of biochemical identification using "Bergey's Manual" (10), these organisms have been classified in six different genera (Table I), with five being identified as to species. These floc-producing organisms were *Zooglea ramigera, Bacillus cereus, Escherichia intermedium, Paracolobactrum aerogenoides, Nocardia actinomorpha,* and a bacterium which appeared to belong to the genus *Flavobacterium*. The isolation of coliform organisms prompted the use of a stock culture of *Aerobacter aerogenes* in the biochemical studies. The stock culture of *A. aerogenes* was supplied from cultures maintained in the laboratory for use in regular classroom instruction.

### Biochemical Tests

After the floc-producing organisms had been isolated and identified, biochemical tests were set up to determine their ability to stabilize organic matter. A synthetic sewage was prepared according to the formula of Weinberger (11). This synthetic sewage had the characteristics of normal domestic sewage and was chosen because of its reproducibility. The B.O.D. of this sewage was found to be approximately 240 p.p.m.

The aeration units used in the biochemical tests are shown in Figure 2. These units were designed on the same principles as the miniature aeration units. The bottles were inverted and had a special drawoff and feed stopcock. Using specially fitted Erlenmeyer flasks, it was possible to draw off the effluent and to feed the units at regular intervals without contaminating the cultures. This permitted the building up of sludge in the aeration units through repeated feedings.

Preliminary studies showed that *B. cereus* was not able to carry the oxidation of organic matter to carbon dioxide and water. For this reason, it was not included. *Z. ramigera* was also omitted from consideration, be-

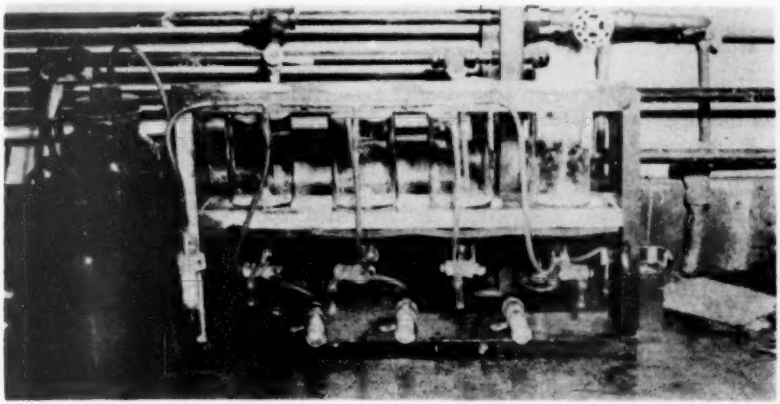

FIGURE 2.—Aeration units used in biochemical studies.

**TABLE I.—Cultural Characteristics of Floc-Forming Bacteria Isolated from Activated Sludge**

| Characteristic | | *Zooglea ramigera* | *Paracolobactrum aerogenoides* | *Escherichia intermedium* | *Bacillus cereus* | *Nocardia actinomorpha* | *Flavobacterium* | *Aerobacter aerogenes* |
|---|---|---|---|---|---|---|---|---|
| No. | Descr. | | | | | | | |
| 1 | Form | Rod | Rod | Rod | Rod | Rod | Rod | Rod |
| 2 | Size (μ) | 0.7×1.5 | 0.7×1.5 | 0.5×1.5 | 1.0×3.0 | 0.7×2.0 | 0.7×1.0 | 1.0×1.5 |
| 3 | Gram stain | 0 | 0 | 0 | + | + | 0 | 0 |
| 4 | Flagella | Polar | — | — | Peri | — | — | — |
| 5 | Capsules | + | + | + | + | + | + | + |
| 6 | Chains | 0 | 0 | 0 | + | + | 0 | 0 |
| 7 | Spores | 0 | 0 | 0 | + | 0 | 0 | 0 |
| 8 | Appearance on agar | White | White | White | White | Chalk white | Yellow | White |
| 9 | Reduction, $NO_3$ to $NO_2$ | + | + | + | + | + | 0 | + |
| 10 | Production of indole | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | Production of $H_2S$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | Reaction on litmus | 0 | Acid | Acid | Basic | Basic | Basic | Acid |
| 13 | Reaction in milk | 0 | 0 | 0 | Pep. | 0 | Sl. pep. | 0 |
| 14 | Reduction of litmus | 0 | + | + | + | 0 | + | + |
| 15 | Liquif. of gelatin | 0 | 0 | 0 | + | + | 0 | 0 |
| 16 | Methyl red | 0 | 0 | + | 0 | 0 | 0 | 0 |
| 17 | Voges-Proskauer | 0 | + | 0 | + | 0 | 0 | + |
| 18 | Growth in citrate | 0 | + | + | 0 | + | + | + |
| 19 | EMB agar | 0 | Mushy | Green metallic sheen | 0 | 0 | 0 | Mushy |
| 20 | Glucose reaction | 0 | A | A | A | 0 | 0[1] | A |
| | Gas | 0 | 50% | 30% | 0 | 0 | 0 | 60% |
| 21 | Lactose reaction | 0 | A[1] | A | 0 | 0 | 0 | A |
| | Gas | 0 | 1% | 15% | 0 | 0 | 0 | 50% |
| 22 | Sucrose reaction | 0 | A | A | A | 0 | 0 | A |
| | Gas | 0 | 70% | 10% | 0 | 0 | 0 | 45% |
| 23 | Starch reaction | 0 | 0 | 0[1] | A | [2] | 0[1] | 0 |
| | Gas | 0 | 0 | 0 | 0 | | 0 | 0 |
| 24 | Mannitol reaction | 0 | A | A | 0 | 0 | 0 | A |
| | Gas | 0 | 60% | 35% | 0 | 0 | 0 | 70% |
| 25 | Salicin reaction | 0 | A | A | 0 | 0 | 0 | A |
| | Gas | 0 | 35% | 40% | 0 | 0 | 0 | 60% |

Note: A = acid.
[1] Delayed acid and gas.
[2] Hydrolysis.

cause so much has already been done with this organism. Data are reported on *A. aerogenes, P. aerogenoides, E. intermedium, N. actinomorpha, Flavobacterium,* and sewage-seeded sludge. Sewage-seeded sludge was carried at all times as a control on the proper operation of the aeration units.

The aeration units were sterilized at 15 p.s.i. for 20 min., cooled, and seeded with the desired organisms. The cultures were aerated for 48 hr., after which aeration was stopped and the sludge was allowed to settle for 1 hr. Then, the supernatant was drawn off and replaced with sterile substrate. The air was started and the process of drawing off the supernatant and replacing it with sterile substrate was repeated several times at 24-hr. intervals. After the sludge began to have a noticeable volume, a time study was made over a 24-hr. period to determine the rate of stabilization of the organic substrate. The results of these time studies are shown in Figures 3 and 4. The suspended solids data are shown in Table II. At the end of

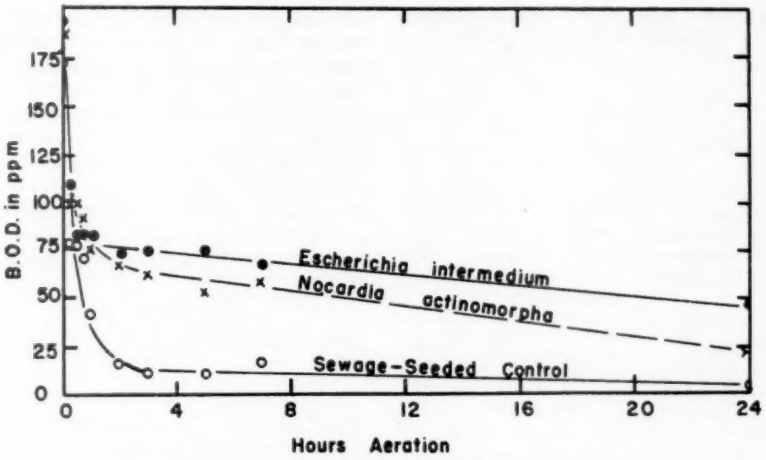


FIGURE 3.—Reduction of B.O.D. by pure culture sludges, run 1.

this time study, microscopic examinations were made to determine the purity of the cultures. None of the pure cultures was found to be contaminated.

## Discussion

From the data it can be seen that the sewage-seeded sludge gave the best B.O.D. removals. In run No. 1 the sewage-seeded sludge gave 99 per cent B.O.D. removal, and in run No. 2 gave 94 per cent removal in 24 hr. of aeration. *Aerobacter aerogenes* gave the lowest B.O.D. removals, 66 per cent in 24 hr. *Paracolobactrum aerogenoides* gave a maximum B.O.D. removal of 76 per cent; *Nocardia actinomorpha,* 88

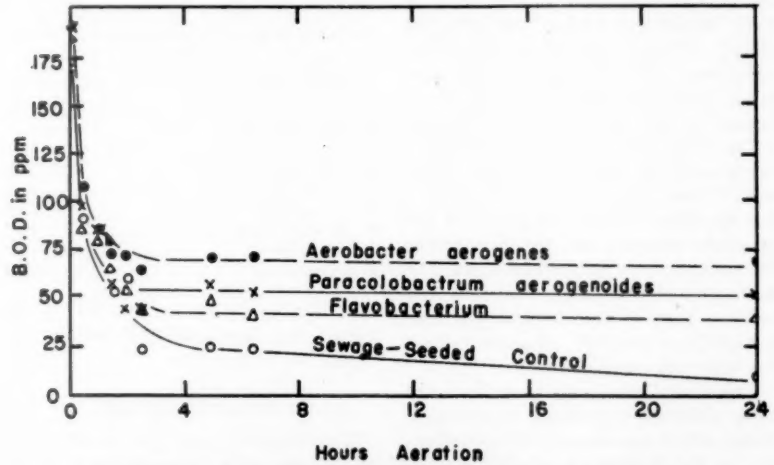


FIGURE 4.—Reduction of B.O.D. by pure culture sludges, run 2.

**TABLE II.—Mixed Liquor Suspended Solids in in Biochemical Studies, in P.P.M.**

| Culture | Time | | Growth |
|---|---|---|---|
| | 0 Hr. | 24 Hr. | |
| (*a*) Run No. 1 | | | |
| Sewage | 290 | 400 | 110 |
| *E. intermedium* | 120 | 400 | 280 |
| *N. actinomorpha* | 350 | 670 | 320 |
| (*b*) Run No. 2 | | | |
| Sewage | 400 | 780 | 380 |
| *A. aerogenes* | 245 | 600 | 355 |
| *P. aerogenoides* | 410 | 1,650 | 1,240 |
| *Flavobacterium* | 495 | 610 | 115 |

per cent; *Escherichia intermedium*, 76 per cent; and the *Flavobacterium*, 78 per cent. In every case almost all of the B.O.D. removed was accounted for within the first 2 hr. of aeration.

With *Z. ramigera* Butterfield (1) reported 72 per cent B.O.D. removals in 3 hr. of aeration in a synthetic substrate. Later studies by Heukelekian (7) gave a range of from 60 to 90 per cent B.O.D. removals in a 24-hr. aeration period. Wattie's results (9) for *Z. ramigera* gave a spread from 36 to 84 per cent with a 3-hr. aeration period. Thus, it can be seen that the organisms isolated in this study compared favorably with *Z. ramigera* as studied by these previous investigators.

The suspended solids concentrations were low by the usual standards. However, it was apparent from the curves that the B.O.D. removals were not too adversely affected by the low solids. The solids were important from the standpoint of furnishing sufficient bacteria to remove the organic material as rapidly as possible. It appears that this task was accomplished.

This study has shown that there are many different organisms in activated sludge which are capable of contributing to the formation of the sludge. Although it has been shown that these organisms give good B.O.D. removals, nothing has been shown as to their relative importance in the normal activated sludge process. The number of variables which might affect the status of each organism in the sludge are very large and will require considerable research before the role of each organism is known. Present laboratory methods may have to be modified and new ones devised for such studies.

## Summary

The results of this study have shown that:

1. It is possible to isolate from activated sludge other organisms than *Z. ramigera* which are capable of forming a floc similar to activated sludge when aerated in a suitable nutrient substrate.

2. The floc-forming organisms isolated, other than *Z. ramigera*, included *Escherichia intermedium*, *Paracolobactrum aerogenoides*, *Nocardia actinomorpha*, *Bacillus cereus*, and a bacterium belonging to the genus *Flavobacterium*.

3. *Aerobacter aerogenes* was also found to form a floc of the same nature as the other bacteria, even though it was not isolated from activated sludge during any of the experiments.

4. The B.O.D. removals over a 24-hr. aeration period using a synthetic sewage substrate were:

| | |
|---|---|
| Sewage-seeded sludge | 94 to 99% |
| *A. aerogenes* | 66% |
| *P. aerogenoides* | 76% |
| *N. actinomorpha* | 88% |
| *E. intermedium* | 76% |
| *Flavobacterium* | 78% |

5. The majority of the B.O.D. removal was accomplished within the first 2 hr. of aeration.

## Acknowledgment

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# CONTROL OF PSYCHODA FLIES AT AKRON *

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Many articles have been written about the control of the trickling filter fly, but if experience at Akron provides even one suggestion of value to another operator the purpose of this paper will have been accomplished.

Fair † has presented a very comprehensive treatise on "The Trickling Filter Fly (*Psychoda alternata*) Its Habits and Control." He states:

A number of different ways have been suggested or are in use for controlling or preventing the development of *Psychoda* in trickling filters. These may be classified as follows:

A. Biological Control.
  1. By natural enemies of *Psychoda*.
    a. Birds and predatory flies.
    b. Spiders and mites.
    c. Parasites.
  2. By animals that compete for the food of *Psychoda*.
    a. Water springtails (*Achorutes viaticus*).
    b. Spiders and mites.
    c. Snails, leeches, and worms.

B. Chemical Control.
  1. By repellents.
  2. By contact insecticides.
  3. By film-destroying compounds.

C. Physical Control.
  1. By burning.
  2. By flooding.
  3. By drying.
  4. By surface barriers and tight walls.
  5. By glass-overs or other covers.

The Akron sewage treatment works was placed in service December 18, 1928. During the summer of 1929 and continuing each year until 1947 the filter fly was a source of considerable nuisance. Its prevalence was partially responsible for damage suits against the city, approximating $130,000 to January, 1951. The filter beds were not constructed to permit flooding, so very little could be done until money became available for insecticide application. The city's sewer service ordinance became effective in February, 1947, thus providing some funds for *Psychoda* control.

## Control Methods Limited

At Akron there are 14 acres of trickling filters with 7 syphon chambers feeding 2 acres each. Burning affected the adults alone. Because of the area of walls and syphon chambers which had to be covered without reaching the larvae it was eliminated. As previously stated, flooding could not be practiced. Resting the beds so as to dry them was tried, but had to be abandoned because of the development of a very strong and disagreeable odor. Consequently, chemical control was the only practical means available.

## 1947 Studies

The control studies were begun during 1946. Based on the work of Carollo*, the work was started with DDT and Rothane in powder form. Each insecticide was mixed with talc and was applied separately to two 8-ft. diameter experimental filters. The filter depth of 9.5 ft. was equal to that of the operating beds at Akron. The applications were at the rate of 50, and then 40 lb., per acre of each insecticide. The DDT was superior to Rothane and the former showed sufficient promise

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; St. Paul, Minn.; Oct. 8–11, 1951.

† See bibliography.

* See bibliography.

to warrant its use on the plant filters during 1947.

Accordingly, applications of a 25 per cent emulsion of DDT were made from May to October, 1947. The composition of the material applied contained the following active ingredients by weight:

| | |
|---|---|
| DDT (dichloro diphenyl trichloroethane) | 25% |
| Aromatic petroleum derivative solvent | 70% |
| Emulsifier | 5% |

The solution had a specific gravity of 1.04.

For part of the season the application was made at the traveling screen house, through which all sewage must pass before being distributed to the syphon chamber of each bed. For part of the time the 25 per cent emulsion of DDT was mixed in a barrel and fed from there; for the balance of the time a Proportioneers feeder was loaned to the plant. The latter method was superior to the barrel application.

The point of application then was switched to the individual syphon chambers.

Application at the traveling screen seemed to be the better of the two methods, but the over-all results for the entire season of 1947 did not prove as good in controlling the insect population as was indicated by the 1946 studies.

During the 1947 work the dose was generally 1 p.p.m., based on a 33-m.g.d. flow. Although varying dosages were used, 1 p.p.m. proved most effective, as well as economically feasible. In all cases the beds remained idle for 2 hr. following the application.

### 1948 Studies

In 1948 it was decided to employ an entomologist for the summer season to give full time to this work and to related studies. An entomologist could not be obtained, but the graduate biologist engaged did an excellent job. His work was divided into two parts—a study of various insecticides and larvicides, and actual full-scale applications to the 14 acres of filters.

Considering the latter first, the traveling screen application was used from May 2 to June 14 with 1 p.p.m. of 25 per cent DDT emulsion concentrate based on 33-m.g.d. flow. By June 14 the insect population on the beds had grown steadily, so the syphon chamber method was tried a second time. This was done as follows: 18 gal. of 25 per cent DDT emulsion concentrate were applied to filter No. 1 at the syphon chamber. As one chamber started to fill, 6 gal. of the emulsion were added at the overflow weir; as the auxiliary chamber started to fill, another 6 gal. were added to its overflow weir; and as the first chamber started to fill again, the third 6 gal. were added. After this third chamber full of sewage dosed with DDT had discharged, one full chamber of sewage without DDT was allowed to discharge. The discharge of one chamber of raw sewage theoretically removed all the DDT remaining in the distribution lines. Then the bed was shut off for 2 hr., with the belief that such a rest period would produce more effective insecticidal results. At the end of the 2-hr. rest period, filter No. 1 was returned to service and filter No. 2 was dosed with DDT in the same manner. The other beds were treated in the same manner, but with varying dosages.

The 6 gal. of 25 per cent DDT emulsion with a specific gravity of 1.04 added to a syphon chamber full of sewage (about 20,000 gal.) gave a strength of about 80 parts of 100 per cent DDT per million gallons of sewage.

Other dosages of 24, 30, and 36 gal. per syphon chamber discharge were tried on the various beds. The increased dosages showed a decided decrease in the adult *Psychodidae* population on the treated beds, but the 30-

gal. application proved to be as good as the 36-gal. and better than the others.

While applying the insecticide by the syphon chamber method, inspections of the beds disclosed the following: In the central portions of each bed nearest to the syphon chamber, no *Psychoda* in either larval, pupal, or adult stages could be observed, but along the outer edges of each bed the fly population continued at a high rate. This condition was observed even on the two filter beds which were receiving weekly doses of 36 gal. of 25 per cent DDT emulsion concentrate.

From a series of samples taken over the beds on which DDT determinations* were made, the results indicated that approximately 75 per cent of the DDT emulsion concentrate was being sprayed onto the area immediately surrounding the syphon chamber (approximately one-third of the bed) and only 25 per cent was being distributed over the remaining two-thirds of the bed.

From the above tests, the efficiency of the syphon chamber method of application was far from what was desired and the need for a surface sprayer rig of some sort was apparent.

### *Fog Application*

During the first week of August, the TNT Exterminating Co., of Akron, was contacted in an attempt to learn more of their methods of combating insects with the "fog" applicator. This fog method is based on a unit known as "T.I.F.A." (Todd Insecticidal Fog Applicator).

In order to obtain some comparison of results obtained from the fog application of DDT, one bed, divided into three parts, was used as a control unit. The division lines ran parallel to surface distribution pipes. The western third of the bed was dosed with a 12.5 per cent DDT concentration. This concentration was composed of 50 parts of 25 per cent DDT emulsion concentrate as obtained from the Standard Oil Co. and 50 parts kerosene. On the middle third, the straight 25 per cent DDT emulsion concentrate was applied. On the eastern third, a 5 per cent DDT solution was used. This was a mixture of 5 per cent DDT in xylene, with 5 per cent by volume of No. 55 crankcase oil in a kerosene base. The "Tifa" gage was set so that the particles of fog dispersion ranged between 60 and 100 microns (0.0025 to 0.0041 in.) This particle size was used for the applications on all three divisions of the control bed.

The total amount of insecticidal solutions (5, 12.5, and 25 per cent DDT solutions) used did not exceed a total of 25 gal., or approximately 8 gal. of each solution.

The "Tifa" unit, mounted on a 6-wheeled 2-ton truck, showed definite advantages and disadvantages. A more thorough application of DDT was effected because of better distribution and deeper penetration than by the syphon method. Only in the 25 per cent area was any effect noted on the larva, but in all three concentrations more flies were killed. On the other hand, the truck was cumbersome, broke a number of nozzles, and impacted the stone. Also, the fog could only be applied when the wind velocities did not exceed 5 m.p.h.

### *Contact Spraying*

Experiments were then conducted with a surface contact sprayer. This consisted of a 55-gal. drum mounted on a tractor equipped with an 11-ft. boom having ⅛-in. holes. The boom was carried horizontally 30 in. above the bed surface. This was replaced early

* "Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists." 6th Ed., p. 86. Assn. of Official Agric. Chemists, P. O. Box 540, Benjamin Franklin Station, Washington 5, D. C.

in 1949 with a farm-type spraying outfit. It was mounted on a 1½-ton truck chassis.

## Tests of Various Insecticides

During 1948 it was felt that the filter flies developed an immunity to DDT. Accordingly, a number of laboratory and filter bed patch tests were conducted with different insecticides.

### *Tests for Adult Knockdown*

Tests for adult kill were tried on laboratory-reared *Psychoda alternata*. The method used was to admit several flies, usually three, into an 80-mm. test tube. A No. 40 filter paper was moistened with the insecticide to be tested, placed over the mouth of the test tube and a rubber stopper inserted. In this manner, only as much insecticide contact surface was exposed to the flies as would cover the surface of the stopper within the test tube. The test tube was then inverted in such a manner that the flies would contact the filter paper at approximately the same time. The "knockdown" time was counted from the time the flies made contact with the filter paper until the flies fell and were unable to coordinate sufficiently to fly. Although a knockdown did not mean immediate death, no flies were observed to recover once the uncoordinated stage was reached, even though the flies were removed from the proximity of the insecticide.

Eight different insecticidal preparations were used. All eight were diluted to a 5 per cent concentration in order to obtain more comparable results between insecticides. Those used in a 5 per cent solution were as follows:

1. DDT (25 per cent emulsion concentrate diluted to 5 per cent with tap water).
2. Chlordane, water emulsion (tap water dilution).
3. Chlordane, oil emulsion (No. 1 fuel oil dilution).
4. Lethane 384, special (No. 1 fuel oil dilution).
5. Lethane 384, agricultural grade (No. 1 fuel oil dilution).
6. Pyrenone, oil emulsion (diluted 1 to 4).
7. Benzene hexachloride (1 teaspoon to 1 qt. water) (6 per cent gamma isomer).
8. Nifos-T (40 per cent tetraethylpyrophosphate) diluted 1/10,000 in water.

Three controls were run simultaneously, as follows:

1. No. 1 fuel oil on filter paper.
2. Kerosene-wetted filter paper.
3. Dry filter paper.

The results of the tests are given in the average number of minutes the insecticides took to bring about a knockdown of the adults, as follows:

| Insecticide | Min. |
|---|---|
| Lethane 384, agricultural grade | 1 |
| Lethane 384, special | 2 |
| Chlordane, oil base | 4 |
| Nifos-T | 6 |
| DDT with water emulsion | 7 |
| Benzene hexachloride | 10 |
| Pyrenone | 14 |
| Chlordane, water emulsion | 29 |

After 1.5 hr. the adult flies in the three controls were still vigorous and flying.

### *Tests on Larvae*

The following insecticides were used to determine their effect on larvae:

1. By volume: Pyrethrum, 10 per cent; Pyrenone, 10 per cent; Lethane 384, special, 20 per cent; kerosene, 60 per cent. Used full strength in the experiment.
2. Nifos-T (Monsanto) 40 per cent tetraethylpyrophosphate; diluted to 1/1,000 with water.
3. Pentachlorophenol; 25 per cent diluted to 5 per cent with kerosene.

**TABLE I.—Comparative Larvicidal Effects of Chemicals Tested**

| Insecticide | | Stopped Feeding (min.) | Inability to Crawl (min.) | Death (min.) |
|---|---|---|---|---|
| No. | Designation | | | |
| 3 | Pentachlorophenol | 0.5 | 4 | 9 |
| 1 | Pyrethrum, etc. | Immed.[1] | 4 | 16 |
| 4 | Lethane | 2 | 11 | 20 |
| 5 | Lethane | 3 | 16 | 52 |
| 6 | Chlordane | 6 | 21 | 66 |
| 8 | Pyrenone | 2 | Almost immed. | 68 |
| 7 | DDT | 4 | Almost immed. | 75 |
| 9 | Pyrenone | 5 | Almost immed. | 95 |
| 2 | Nifos-T | Almost immed. | Immed.[2] | None[3] |
| 10 | Hexachloride | None | None | None[3] |

[1] Immediately.
[2] Stopped crawling immediately, but much coiling and twisting.
[3] Not dead after 2 hr.

4. Lethane 384, agricultural grade; diluted to 5 per cent in kerosene.

5. Lethane 384, special; diluted to 5 per cent in kerosene.

6. Chlordane; diluted to 5 per cent in kerosene.

7. DDT, oil emulsifiable; diluted to 5 per cent in kerosene.

8. Pyrenone; diluted 1 to 4 by volume in kerosene.

9. Pyrenone; diluted 1 to 4 by volume in water.

10. Benzene hexachloride (6 per cent gamma isomer); dilution, 1 teaspoon to 1,000 ml. of water (2.2 g.)

In this test the times recorded were those after immersion until the larvae stopped feeding, when inability to crawl occurred, and when death resulted. The various times (Table I) are for an average of 10 larvae used in each test. The results were gathered from as near to average larvae as possible.

In Table I the number in the insecticide column represents the number given to the specific insecticide in the above listing. The results are listed in the order of the times in which the death of the larvae occurred, with the shortest time given first. In the "Stopped Feeding" and "Inability to Crawl" columns, the time is from exposure to the insecticide until the occurrence.

*Tests with Mixtures*

It is self-evident that if the *Psychodidae* larvae could be controlled there would be no adult fly problem. As DDT did not prove to be a sufficiently lethal larvicide by itself, various concentrations of several different insecticides were prepared and applied to various test plots of the control bed. This work was conducted while running the previously mentioned laboratory experiments.

The insecticides used in these tests were mixed in various concentrations in order to obtain the greatest efficiency with maximum economy, in the event one would be found which might be used on a full plant scale. The insecticides used in one or several of the mixtures were: Pentachlorophenol, Lethane 384 (special and agricultural grades), DDT (25 per cent emulsion concentrate and technical grades), benzene hexachloride (6% gamma isomer), pyrethrum, and Pyrenone. Most of the tests were conducted with a "Hi-Fog" applicator. This is the commercial name for a man-carried, single nozzle sprayer, which holds approximately 1

gal. of solution. In each test plot the knockdown of adult *Psychodidae* and the effect of each solution upon the larval and pupal stages were observed closely.

A mixture of 5 per cent Pentachlorophenol, 10 per cent Lethane 384 (agricultural grade), and 10 per cent DDT (technical grade) gave the best over-all results. The weak feature of this solution, however, was the comparatively high cost per gallon.

The results of the 1948 experiments showed that better control of the *Psychodidae* could be effected by the use of a mixture of three insecticides than had been obtained through the use of DDT alone. These three insecticides are Pentachlorophenol, Lethane 384 (agricultural grade), and DDT (technical grade).

Pentachlorophenol was by far the most potent larvicide that had been tested to date.

Lethane 384 (agricultural grade) gave the best results of adult fly knockdown, both in the laboratory and in filter bed test plots. This insecticide also had a rather potent lethal effect on larval and pupal stages.

The technical grade of DDT (100 per cent dichloro diphenyl trichloroethane) was incorporated in this insecticide preparation for several reasons. Although the two other ingredients of the mixture are quite lethal to the *Psychodidae* their potency is not too effective over a long period of time. Because DDT is known to have an extremely long lethal residual, its use in the mixture appeared essential.

DDT is a rather slow-working insecticide, but if the insects could be knocked down quickly for even a short period by the two other insecticides, the DDT would have sufficient time to effect a complete kill.

The results of all the experiments performed during 1948, using 14 insecticides in various concentrations, indicated that a combination of the three aforementioned compounds gave the most outstanding *Psychoda* control. They were combined in the following percentages:

| | |
|---|---|
| Pentachlorophenol | 5% |
| Lethane 384 (agri. grade) | 10% |
| DDT (technical grade) | 10% |

Such high percentages would make the cost of application prohibitive. Further tests with mixtures containing 3 per cent Pentachlorophenol, 5 per cent Lethane 384 (agricultural grade), and 5 per cent DDT were tried. Although this mixture of lesser percentages showed a decrease in control from the high percentage mixture, the results obtained were still superior to the regular applications of 25 per cent DDT, both in control of the *Psychoda* and economically.

By the end of the 1948 season work had been completed on a full-scale basis with the water emulsion of DDT, the Pentachlorophenol-Lethane-DDT mixture using No. 2 fuel oil as a diluting agent, and with fuel oil alone. The latter was used in the belief that it would suffocate the larvae, but it was not very effective.

### 1949 Studies

In 1949 the application of insecticide started on June 6 with a farm-type surface sprayer equipped with 20 nozzles spaced 20 in. apart on a 33-ft. boom and using a 5 per cent water solution of DDT. It was quickly apparent that a different insecticide had to be used. Accordingly, on June 20 a change was made to a mixture of 9 per cent Pentachlorophenol powder, 15 per cent Lethane 384 liquid, 15 per cent DDT (technical) powder, and 61 per cent organic solvent mixed by a local exterminating company. This was diluted to a 3–5–5 concentration with No. 2 fuel oil, as the latter provided better adhesion to the filter stone.

Applications were made every 7 days, but this interval had to be reduced to 5 days. The over-all seasonal results were better than with DDT alone, but before the season ended convincing evidence was presented that this second insecticide was not the final answer.

Accordingly experiments were conducted with Chloroben and Herbicide. The former showed some promise as a larvicide, but was not sufficiently effective to replace the combination of Pentachlorophenol, Lethane, and DDT. Herbicide proved to be an ineffective contact insecticide. Being arsenical in composition, its value lies in its use where a stomach poison is needed.

During 1949 the filters developed a small, nervously active, dark-colored phorid fly, later identified as a species of *Megaselia*. These increased in number and predominated until August, when the *Psychoda* again were dominant. This is only the second time in 22 years that this black gnat has given trouble. Although the larvae were found in the filter beds, the real origin was not determined. The insecticides used did not affect this insect as much as they did the *Psychoda*. By the end of the 1949 season it was evident that a third insecticide and larvicide was essential. In other words, it appeared as though rotation of insecticides was the answer to the control problem.

### 1950 Work

On May 8, 1950, dosing of the beds with Pentachlorophenol, Lethane, and DDT was begun on a weekly basis, but on May 29 a change was made to a water emulsion of benzene hexachloride containing 11 per cent gamma isomer, which Hood found effective at Ridgewood, N. J. The BHC previously used at Akron contained 6 per cent gamma isomer and showed no promise whatsoever.

The Akron application of BHC was at the rate of 4.5 gal. per acre. Eight days after the first application a second was made. It was not necessary to make a third application until three weeks later, as against 5 to 7 days with the other insecticides. No further application was required during 1950.

Checks with 6-in. squares of fly paper, placed at the edge of the filters and approximately 150 ft. to the windward, gave a zero daily count throughout 1950 after July 1.

### Additional Comments

Up to July 1, 1951, the only development of larvae and adults occurred about the third week in June in the edge areas where the stones are just moist or completely dry because the half nozzles prevent wetting of this area. These areas were treated in the usual manner with excellent results.

Various other existing operating conditions should be mentioned here, so as to note their possible effect upon the insecticide test results. On August 9, 1949, the Akron plant began chlorination for odor control by applying chlorine to the raw sewage and filter influent. It was not in sufficient quantities to carry a residual in the filter influent, except on very rare occasions, and then for short intervals only.

To prevent filter bed ponding it had been the custom at Akron to harrow the filters once a year with a spike-tooth harrow, which penetrated the stone about 4 or 5 in. In 1949 the practice was begun of harrowing in early spring and late fall with a shop-made harrow using spikes of 1¼-in. hexagon cold-rolled steel properly pointed. The spikes are 14 in. long and by weighting the harrow they penetrate to a depth of approximately 10 in.

In 1951 it was observed that a black sludgy deposit was present on a large portion of the 14-acre area and that no larvae appeared where the black deposit was present. The deposit has

not caused more than the usual few small spot-ponded areas.

At the Cleveland, Ohio, Southerly sewage treatment works, the filters are badly clogged. The superintendent, Walter Gerdel, states that they have had no flies since this condition has existed (approximately six years).

### Trial at Second Plant

Believing that the combination of harrowing, chlorination, insecticide applications, and sludge-like deposits might have affected the Akron results with BHC alone, recommendations were made for the use of BHC at a small treatment plant which the writer supervises near Akron and where no other element enters the picture. Strictly domestic sewage is settled and then flows onto two filters equipped with rotary distributors. Each filter is 48 ft. in diameter and 4.5 ft. deep.

In 1950, one dose of BHC at the rate of 4.5 gal. per acre did an excellent job at this plant, but as this was near the end of the year it was the only application made.

In 1951, one dose of double the rate was applied on May 29. There was a sufficient development of *Psychoda* and eggs, but no larvae, to require a second dosage of 4.5 gal. per acre exactly 30 days later. More recent observation indicated that this rate of application is effective for from 4 to 5 weeks.

### Effect on Filter Efficiency

The average analyses of the Akron trickling filter effluent for 3 years prior to the application of any insecticide and for the 3 years during application were as follows:

| | Before | After |
|---|---|---|
| Susp. sol. (p.p.m.) | 137 | 106 |
| B.O.D. (p.p.m.) | 58 | 41 |
| $NO_2$ and $NO_3$ (p.p.m.) | 1.8 | 0.8 |
| Rel. stab. (%) | 50 | 60 |

These results seem to indicate that the filter efficiency was not impaired.

### Summary

Briefly summarizing Akron's experience it may be stated that:

1. Harrowing has been practiced annually for years, but in 1949 a change was made to doing this each spring and fall and the penetration into the stone was increased from 5 in. to about 10 in.
2. Chlorination of the raw sewage and filter influent for odor control began August 9, 1949.
3. A black deposit appeared on a large portion of the filter beds early in 1951. In these areas the *Psychoda* larvae and flies were noticeable by their absence.
4. Plant-scale treatment with insecticide was begun in 1947 and is being continued as needed.
5. Plant-scale applications were made as follows:
   (a) To the trickling filter influent at the outlet end of the Imhoff tanks and to the 7 individual dual syphon chambers.
   (b) To the filter beds with a fog applicator.
   (c) To the filter beds with a contact or surface sprayer, which was driven over the beds' surface.
   (d) During the entire seasons of 1947 and 1948 DDT was applied to the sewage, generally at the rate of 1 p.p.m. based on the design flow rate of 33 m.g.d.
   (e) During 1949, 1950, and 1951 the surface or contact sprayer was used exclusively. All insecticides were applied at the rate of 4.5 gal. of the concentrated material per acre, followed in all cases by a 2-hr. rest period.

(f) In 1949 a DDT 25 per cent emulsion concentrate diluted with water; a mixture of 3 per cent Pentachlorophenol, 5 per cent Lethane, and 5 per cent DDT diluted with No. 2 fuel oil; and No. 2 fuel oil alone were used.

(g) In 1950, the Pentachlorophenol mixture was used for a few weeks, followed by benzene hexachloride containing 11 per cent gamma isomer. The latter has been used since then when needed.

6. To indicate the magnitude of the endeavors described herein it may be well to mention that to date $21,348 has been spent for insecticides and major equipment alone. This may be divided as follows:

| | |
|---|---|
| Spraying equipment | $975 |
| DDT emulsion conc. | 10,105 |
| Pentachlorophenol mix. | 6,000 |
| BHC | 3,512 |
| Fuel oil | 756 |

## Conclusions

1. Benzene hexachloride with 11 per cent gamma isomer appears to be a relatively positive insecticide and larvicide for control of the *Psychoda* flies found in trickling filters.

2. It appears to be very effective at the rate of 4.5 gal. per acre.

3. It should be applied very early in the season at double the normal rates.

4. Although more expensive per gallon than any insecticide used at Akron, it was the most economical because of the longer period of effectiveness between dosages.

5. It appears that a 2-hr. resting period after each dosage is ample time for complete contact.

6. A wet application with sufficient pressure to force the solution a little below the immediate surface increases its efficiency.

7. From an operating angle, chemical applications appear to be preferable to flooding because:

(a) At small plants flooding requires many hours to fill the filter.

(b) At an installation where there is only one filter and one daytime operator, an overflow must be provided so the discharge from the bed equals the inflow in order to keep all the filter media submerged. Otherwise, the sewage will spill over the filters walls unless an automatic by-pass is provided.

(c) After flooding, the filter unloads and the efficiency of the filter drops for a few days.

(d) Flooding must be accomplished in the Akron area every 7 days for reasonable control.

(e) The kill from flooding is not as great as with 11 per cent gamma isomer BHC.

8. Apparently the insecticides used at Akron do not affect the trickling filter efficiency.

9. A final solution for as complete control as is possible may be found by rotating insecticides to overcome the tendency of the filter fly to become immune to a specific insecticide.

10. Harrowing did not affect the over-all Akron situation. However, the black deposit and chlorination may have, as BHC alone at a normal plant under the same climatic conditions provides a practical elimination of *Psychoda* for only 4 or 5 weeks.

Although very few references are given in this paper, the complete bibliography compiled by Paul Ritty, who did much of the Akron experimental work, might be of interest and, therefore, is included.

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# VENTILATION OF TRICKLING FILTERS*

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The biological process contained in the action of the trickling filter is generally characterized as an aerobic process; consequently air or oxygen is required to maintain aerobic conditions. This air is supplied to the filter by natural or mechanical methods of ventilation. However, regardless of the seeming importance of ventilation, relatively little is known regarding:

1. The optimum air flow requirements of a filter.
2. The mechanism of air flow through a filter under field conditions.

This latter problem prompted an investigation by the writer to observe the natural forces causing and influencing the flow of air in trickling filters under field conditions. Before presenting the experimental data it may be well to discuss briefly how ventilation may affect the efficiency of a filter.

## Effect of Ventilation on Trickling Filter Efficiencies

Trickling filters have reportedly operated efficiently without an apparent supply of oxygen or air. Hatfield (1) stated, "Decatur filters operate by gravity and at certain stages of the river have operated with one or two feet of the stone submerged for periods of two to three weeks without any considerable deterioration of the effluent. In fact they have operated fairly well with three feet of the stone submerged." Such observations have created some doubt as to the necessity for ventilation. However, conclusive proof of the value and need of ventilation was given by Levine (2) from experiments on filter models operated to treat skim milk wastes. He found, among other things, that when bottom ventilation was eliminated the B.O.D. removal by the filters was relatively low and the filters tended to clog. These results seem to contradict the observations by Hatfield, as the flooded Decatur filters had no bottom ventilation. The experimental data obtained by this writer indicate the Decatur filters obtained oxygen due to wind action, whereas the filter models were operated in a laboratory and not exposed to drafts.

Some investigators have advanced the theory that the carbon dioxide produced by bacterial respiration within the bed may be toxic to the organisms if present in sufficient concentration. If so, ventilation may serve to "sweep out" the carbon dioxide.

It is often believed that excessive ventilation during the cold winter season may cool a filter bed to a point where the efficiency is impaired. This may be true with uncovered beds, but in most localities where the winters are quite cold the filters are housed to limit the air flow. On a filter model Piret (3) found that the media, and thus the biological film, approached the liquid or sewage temperature. By considering the specific heats of water and air together with some average filter operating data and a reasonable air flow of 1.5 cu. ft. per min. per square foot of filter area, the effect of cooling by ventilation may be illustrated. It may be found that with an initial tem-

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perature differential between the sewage and the air outside the filter of 50° F., the liquid may be cooled only 1° F. while the air is heated approximately 50° F. as it passes through the bed. Thus, since ventilation is not likely to have much effect on the temperature of the biological film it will not likely impair the efficiency due to any cooling.

### Amount of Air or Oxygen Required

To give more meaning to the experimental data an estimate of the air or oxygen requirements of a trickling filter is in order. The best estimate of air requirements must be based on the reduction in ultimate B.O.D. by oxidation in the filter. According to Ziemke (4), of the total B.O.D. reduction by the filter and final tank, 85 to 90 per cent may actually be by oxidation in the filter alone.

If 0.124 lb. of ultimate B.O.D. are removed by oxidation in a 6-ft. deep filter per square foot per day (based on a loading of approximately 1,500 lb. B.O.D. per acre-foot per day), the air flow requirements may be computed. By assuming the unit weight of air as 0.0750 lb. per cu. ft. and that the air contains 23 per cent oxygen, the air flow requirements are:

$$\frac{0.124}{1{,}440 \times 0.0750 \times 0.23}$$

$$= 0.005 \text{ cu. ft. per min. per sq. ft.}$$

There is a possibility that only a small portion of the oxygen passing through the bed may be assimilated by the organisms (5). Indications (6) are that this portion may be only 5 per cent of the total oxygen passing through the bed; thus, the above air flow becomes:

$$\frac{0.005}{0.050} = 0.100 \text{ cu. ft. per min. per sq. ft.}$$

From the experimental data it will be found that such air flows are easily obtained by natural ventilation.

From consideration of the saturation values of dissolved oxygen in sewage it may be found that of the oxygen required by the filter organisms only a small percentage may be supplied from oxygen dissolved in the sewage by the spraying action on the bed or other means of aeration. Therefore, most of the oxygen must be supplied by ventilation.

### Mechanism of Natural Ventilation

Natural ventilation is a result of a natural draft or pressure differential existing between the air in the atmosphere and the air inside the filter structure. As the pressures attempt to reach equilibrium a flow of air occurs and ventilation is accomplished. The two primary causes of natural drafts and ventilation are:

1. Differences in air densities between the air inside and outside the filter.
2. Wind forces.

A natural draft due to air density differences is often termed a "stack effect." For trickling filters, the air in the filter structure and media is heated or cooled by the sewage as the sewage is warmer or colder than the air outside. Depending on the season, it is apparent that this stack effect is likely to cause a flow of air up through the media in the cold winter season and down through the media in the hot summer time. This effect is illustrated in Figure 1, where the average temperatures of the air in the four sections of the filter are represented by $T$ and the average air densities are given as $W$. It is evident that if the filter structure were sealed at point B and open at point A (no air flowing) the pressure differential, or draft, or head $h$, would be:

$$h = (W_1H_1 + W_2H_2) - (W_3H_1 + W_4H_2).$$

This pressure differential is maintained only as long as the air is heated or

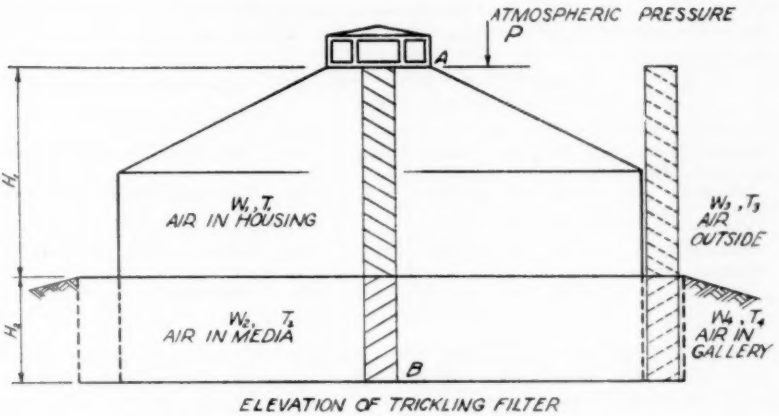


**FIGURE 1.—The stack effect in a trickling filter.**

cooled in the filter at a rate to maintain the density differences.

Water in air causes a decrease in the air density, but the influence of humidity on the draft in a filter is relatively small. For housed units the daytime heating of the housing by the sun tends to heat the air in the housing, resulting in increasing the upflow or decreasing the downflow of air through the media. The heat of reaction by organisms in the bed may be considerable, but it is logical to assume that most of this heat is given up to the sewage by conduction and not to the air; thus, such heat has little effect on the air densities.

Because humidity, solar heating on housings, and the heat of reaction by organisms tend to decrease a downflow of air, the entire summer season may be a critical period from the standpoint of having adequate ventilation provided by a stack effect. A laboratory study of the air flow through a model trickling filter, made by Piret (3) in cooperation with Halvorson and Mann (7), illustrated this draft due to air density differences.

The probable effect of ventilation due to the wind has been mentioned frequently, but no conclusions have been reached. Randall (8) states that "wind is the chief motive force utilized in the aeration of a building by natural means." For a filter without a housing the wind is likely to cause air circulation due to a "jump effect," whereby the wind streamlines hit the windward wall of the filter and "jump" up and over a windward area of the bed. This area of decreased pressure on the windward side of the bed, coupled with increased pressure on a downwind area, should result in air circulation within the filter media. Because of the extreme variability of the wind it has often been discounted, but actually there seldom is a day of absolute calm and a well-exposed filter may be ventilated by the wind alone. On the basis of data obtained in the operation of packed absorption towers, the comparatively low dosing rates used on trickling filters are not likely to influence the air flow appreciably. This discounts a common belief that, due to a dragging effect of the liquid on the air, air is pulled down through the filter. Piret (3), together with Halvorson and Mann (7), found that intermittent dosing lessened the stack

TABLE I.—Plant Descriptions of Trickling Filters Studied

| Plant | Diam. (ft.) | Depth (ft.) | Media | | Housing | Gallery Location | Type of Dosing |
|---|---|---|---|---|---|---|---|
| | | | Type | Size (In.) | | | |
| Excelsior, Minn. | 54 | 8 | Rock | 2–2½ | Yes | Half of periphery | Intermittent |
| Owatonna, Minn. | | | | | | | |
| Secondary | 55 | 6 | Rock | 2–3 | Yes | Half of periphery | Continuous |
| Kenyon, Minn. | | | | | | | |
| Primary | 43 | 6 | Tile | — | Yes | Half of periphery | Continuous |
| Secondary | 30 | 6 | Rock | 2½–3 | Yes | Half of periphery | Continuous |
| Plainview, Minn. | | | | | | | |
| Secondary | 55 | 6.2 | Rock | 2½–4 | No | Along diameter | Intermittent |

effect in a filter, due to the rest periods when the temperature of the media would more closely approach the outside air temperature. However, with shorter rest periods this effect becomes relatively small.

## Experimental Work

The experimental data were observed at four different sewage treatment plants in Minnesota. Inasmuch as most of the trickling filters in Minnesota are housed or covered, it was possible to obtain data from only the one open bed at Plainview, Minn. All plants were very well-operated and the operators were very cooperative. Table I gives plant descriptions.

## Measurements

Data for determining the air densities were taken in order to compute the draft due to the stack effect. With a housed filter the average air densities were computed for the outside air, the air in the housing, the air in the gallery or tunnel, and the air in the media. The data required to compute the air density were the dry-bulb and wet-bulb temperatures, together with the barometric pressure. The barometric pressure was observed wih an aneroid-type barometer and recorded to the nearest 0.01 in. of mercury. The temperatures were taken to the nearest 0.1° F. with a sling psychrometer.

Air velocity readings were taken with a hot-wire anemometer accurate to 20 ft. per min.; for cold-weather data a deflecting vane velocity meter was used, which was accurate only to 30 ft. per min. With these instruments the surface wind velocities were observed, together with air velocities within the filter to determine the total air movement through the filter. The latter readings were taken at the underdrain ports in the filter walls when using the hot-wire anemometer. The deflecting vane velocity readings were taken as profiles across a section of the gallery.

To check computed drafts and to attempt to obtain the actual draft on windy days, draft gage (differential manometer) readings were taken. A Wahlen gage (Illinois micromanometer) was used, which permitted draft observations to an accuracy of 0.001 in. of water. The total available draft or head was obtained by sealing the entrance to the gallery or tunnel to prevent a flow of air through the filter. Under such conditions the entire available head manifests itself as a differential reading on the gage by connecting one pressure tap through a hole to the inside of the gallery and the other to the atmosphere.

The Wahlen gage was also used to determine head losses through the openings in the gallery and through the top of the housing in the case of closed filters. Such head loss readings

were taken only at the Excelsior and Owatonna plants when the total available head was quite high (in the winter season).

### Presentation of Data

To show the effect of air density differences in producing drafts, the data taken when the surface wind velocities were 2.0 mi. per hr. or less were considered separate from the other data, as it was assumed that such low wind velocities had little effect on the draft. Data prepared for analysis were:

1. Total air flows.—The total air flow was found by multiplying the average air velocity in the underdrain wall ports by the total area of the wall ports. The bulk air flow (numerically equal to the bulk air velocity) over the entire bed was found by dividing the area of the bed into the total air flow and recorded in cubic feet per minute per square foot of filter area. Positive values indicate that upflow existed and negative values indicate downflow.

2. Theoretical draft.—From air density data the draft due to air density differences or the stack effect was computed to the nearest 0.001 in. of water and is represented herein as the "theoretical draft."

3. Temperature differences. — Be-

**TABLE II.—Summary of Experimental Data from Excelsior, Minn.**

| Run No. | Wind Vel. (m.p.h.) | Temp. (° F.) | | | Draft (in. of water) | | Air Flow (c.f.m.) | |
|---|---|---|---|---|---|---|---|---|
| | | Outside Air, $O$ | Sewage, $S$ | Diff. (° F.) $S - O$ | Theor. | Actual | Total, $Q$ | Per sq. ft. |
| 1 | 0 | 75.0 | 59.0 | −16.0 | −0.003 | — | −554 | −0.242 |
| 2 | >2.0 | 72.5 | 62.5 | −10.0 | 0 | — | 730 | 0.319 |
| 3 | 0 | 62.0 | 61.5 | − 0.5 | 0.004 | — | 584 | 0.255 |
| 4 | >2.0 | 83.0 | 62.5 | −20.5 | −0.003 | — | 540 | 0.236 |
| 5 | >2.0 | 76.0 | 64.9 | −11.1 | −0.002 | — | 496 | 0.217 |
| 6 | 0 | 75.0 | 64.5 | −10.5 | −0.001 | — | −408 | −0.179 |
| 7 | 0 | 83.0 | 65.0 | −18.0 | −0.002 | — | −496 | −0.216 |
| 8[1] | 0 | 69.5 | 65.0 | − 4.5 | −0.001 | −0.010 | −263 | −0.115 |
| 9[1] | 0 | 73.0 | 64.5 | − 8.5 | −0.001 | −0.008 | −350 | −0.153 |
| 10[1, 4] | <2.0 | 77.5 | 64.0 | −13.5 | −0.001 | −0.006 | ±350 | ±0.153 |
| 11[1] | <2.0 | 79.0 | 65.0 | −14.0 | 0 | 0.002 | 394 | 0.172 |
| 12[2] | 3.4–5.7 | 66.5 | 66.5 | 0 | 0.004 | 0.009 | 744 | 0.325 |
| 13[2] | 3.4–5.7 | 66.2 | 66.5 | 0.3 | 0.004 | — | 569 | 0.248 |
| 14[2] | 2.3–8.0 | 68.5 | 66.5 | − 2.0 | 0.003 | 0.005 | 613 | 0.268 |
| 15[2] | 2.3–3.4 | 69.5 | 67.2 | − 2.3 | 0.004 | 0.005 | 438 | 0.191 |
| 16 | 0 | 69.6 | 67.6 | − 2.0 | 0.003 | 0.005 | 453 | 0.198 |
| 17 | 1.7–5.7 | 42.0 | 63.0 | 21.0 | 0.008 | 0.008 | 1,163 | 0.508 |
| 18 | 2.3–5.1 | 46.0 | 63.5 | 17.5 | 0.007 | 0.011 | 730 | 0.318 |
| 19[3] | 2.8–5.1 | 50.5 | 58.0 | 7.5 | 0.003 | 0.006 | 467 | 0.204 |
| 20[3] | 0 | 41.2 | 58.2 | 17.0 | 0.007 | 0.006 | 526 | 0.230 |
| 21 | 0 | 10.0 | 49.3 | 39.3 | 0.025 | 0.024 | 1,316 | 0.574 |
| 22 | 0 | 10.6 | 47.0 | 36.4 | 0.024 | 0.026 | 1,220 | 0.532 |
| 23 | 0 | −8.9 | 49.6 | 58.5 | 0.037 | 0.036 | 1,600 | 0.699 |
| 24 | 0 | 12.5 | 49.7 | 37.2 | 0.022 | 0.022 | 1,306 | 0.570 |

[1] Draft readings questionable due to orientation of gage.
[2] Bed only partially used as a result of other experiments.
[3] Distributor not revolving.
[4] Data not used.

cause air density is primarily a function of the air temperature, the temperature differences between the sewage and the outside air (sewage temperature minus the outside air temperature) were computed to represent the draft under conditions of low wind velocity. Without considering the effect of humidity and wind it may be noted that a positive difference indicates that the air should move up through the bed and a negative difference indicates downflow (because cold air is heavier than warm air).

4. Actual draft and head losses.—Actual drafts and head losses observed with the Wahlen gage were computed to the nearest 0.001 in. of water. Both actual and theoretical drafts were given a positive sign if they were indicative of causing flow up through the filter bed and a negative sign if they indicated that downflow should exist.

Units used are:

$h$ = total draft or head, in inches of water.

$V$ = bulk air flow (bulk air velocity), in cubic feet per minute per square foot of filter area.

$D$ = sewage temperature minus the outside air temperature in degrees Fahrenheit.

$h_m$ = draft or head loss through trickling filter media per foot of depth, in inches of water.

## Analysis of Data

*Excelsior, Minn.*

The most extensive data were taken at the Excelsior, Minn., plant. Table II is a summary of the experimental data from that plant. Twenty-four

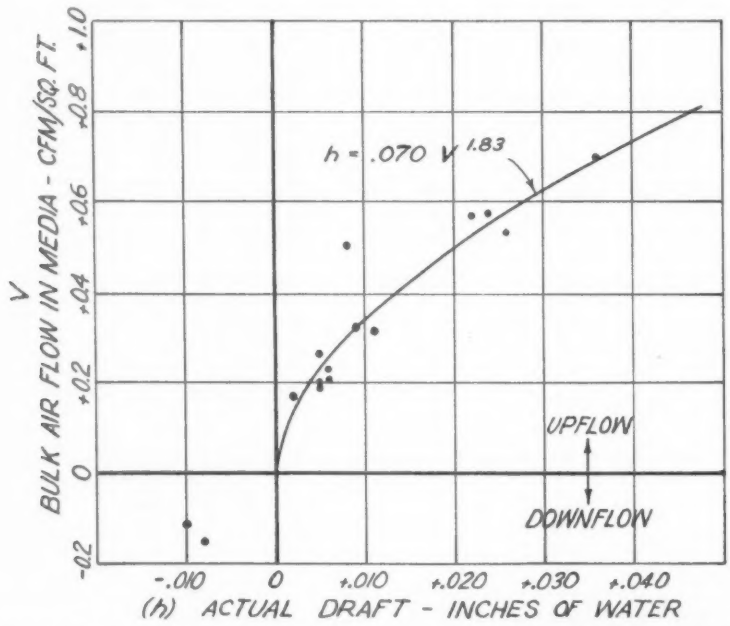


FIGURE 2.—Relationship between total draft and bulk air flow in trickling filter at Excelsior, Minn.

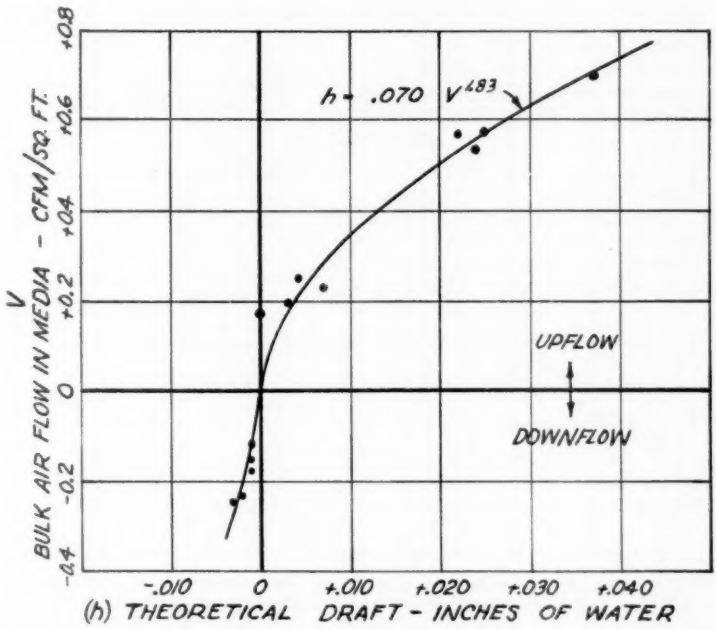


**FIGURE 3.—Relationship between total theoretical draft and bulk air flow in trickling filter at Excelsior, Minn.**

separate runs were conducted, with the outside air temperature ranging from 83° F. to − 8.9° F. For 10 runs the surface wind velocity ranged from 2.0 to 8.0 m.p.h.; for the remaining 14, it was less than 2.0 m.p.h. Due to contingent factors, varying from observational errors to conditions prohibiting the taking of true observations, some runs may not include a complete set of data.

Figure 2 shows the relationship between the total (actual) draft and the bulk air flow. It is evident that most of the data were taken when upflow occurred in the filter. These data include observations under all conditions of wind velocity where the actual draft could be measured. The equation of the curve is:

$$h = 0.070\ V^{1.83}.$$

To show the effect of air density differences in inducing air flow, Figure 3 has been plotted for the theoretical draft and the bulk air flow for wind velocity conditions of less than 2.0 m.p.h. The curve from Figure 2 fits the data for flow up through the media quite well and the data for downflow show a similar relationship. Thus, with the air density differences as the only factors causing drafts, it is evident that such resulting forces are important factors in adequately ventilating trickling filters.

Because the draft in a filter cannot be measured easily, the sewage temperature minus the outside air temperature was taken as a rough indication of the draft and plotted versus the bulk air flow in Figure 4. Although the data are quite scattered, as may be expected, the straight line shown describes the data quite well. Because such a curve may be drawn,

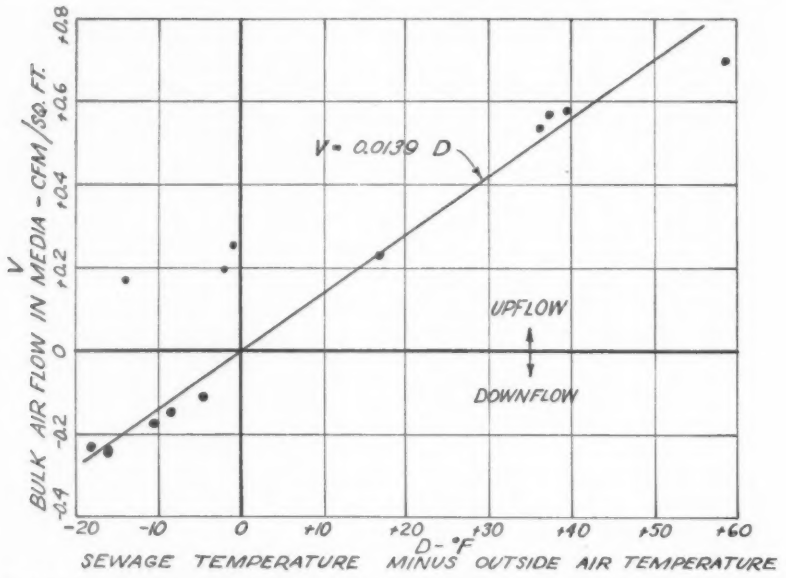


**FIGURE 4.—Relationship of difference in temperature between sewage and outside air and the bulk air flow in Excelsior, Minn., trickling filter.**

it may be concluded that the temperature difference between the outside air and the sewage is indicative of the draft and air flow resulting from the stack effect alone.

If theoretical draft data observed when the wind velocities were 2.0 to 8.0 m.p.h. were plotted against bulk air flows (as in Figure 3), a wide scatter of points would result to show that under windy conditions the drafts due to air density differences are supplemented by the action of the wind to cause ventilation. If the curve of Figure 3 was included on such a plot it would generally be below and to the right of the data, showing that the effect of the wind is to cause upflow in the filter. If it were possible (and in many cases it was not) to accurately measure the actual draft under windy conditions, all the points would be shifted to the right to fall very close to the curve.

Four runs included head loss observations through the opening to the gallery and the opening at the top of the housing. These two head losses, subtracted from the total head or draft, gave what was considered as the loss through the underdrains and the media. An attempt was made to compute head losses in the various sections of the filter and compare them with the observed data. From data by Piret (3) for bulk air flows of 0 to 1.5 cu. ft. per min. per sq. ft., an approximate straight line relationship may be found to exist to represent the loss through the media and the top of the underdrains. This relationship is

$$h_m = 0.111 \times 10^{-3}\ V.$$

For other sections of the filter reasonable orifice coefficients seemed to apply and the computed and observed losses for one run are given in Table III in inches of water, where *O*

indicates the observed loss and *C* the computed loss:

**TABLE III.—Head Losses (in Inches of Water) in Excelsior, Minn., Filter**

| Gallery Manhole | | Rock and Underdrains | | Opening in Housing | | Total Head | |
|---|---|---|---|---|---|---|---|
| *O* | *C* | *O* | *C* | *O* | *C* | *O* | *C* |
| 0.001 | 0.001 | 0.001 | 0.001 | 0.020 | 0.022 | 0.022 | 0.024 |

For the Excelsior filter it seems that ventilation may be increased considerably by enlarging the opening in the top of the housing, as the greatest head loss occurs at that point.

*Owatonna, Minn.*

Only 10 sets of observations were taken at the Owatonna, Minn., plant. The surface wind velocity ranged from 2.0 to 20 m.p.h. for 9 runs, and was less than 2.0 m.p.h. for only one run. Outside air temperatures ranged from 79° to 3° F. A curve similar to Figure 2 for Excelsior was found for the Owatonna plant to have the equation (see Figure 6)

$$h = 0.032\ V^{1.60}.$$

Although the theoretical draft was negative or of a small positive magnitude for five runs, the air flow in all cases was found to be up through the media. This again indicates that the wind is likely to induce a positive draft to cause upflow through a housed filter.

Because only one run was taken under conditions of low wind velocity, no correlation could be made between the bulk air flow and the draft due to air density differences as indicated by the temperature difference between the outside air and the sewage.

Three runs included data on head losses through the filter and the construction was such that the head losses through the opening in the housing were relatively less than those found at the Excelsior plant.

*Kenyon, Minn.*

In an attempt to determine the relative effect of tile media and rock media on ventilation, three runs were conducted where data was taken on both filters at the same time. One separate run was taken on each filter. Only one run was taken with the wind velocity over 2.0 m.p.h.

A plot of the data from both filters indicates no apparent difference in the ventilation characteristics through the two filters. The curve for the Kenyon filters comparable to the curve of Figure 2 for Excelsior was found to have the equation (see Figure 6)

$$h = 0.006\ V^{1.55}.$$

The curve of the above equation described a plot of the theoretical draft versus the bulk air flow very well, again showing the stack effect as the major cause of natural draft and ventilation.

A plot of the sewage temperature minus the outside air temperature *versus* the bulk air flow showed excellent correlation with the straight line (see Figure 7)

$$V = 0.0519\ D.$$

For the one run conducted under windy conditions the actual draft was of greater positive magnitude than the computed theoretical draft, indicating that the wind is likely to cause an upflow of air through a housed filter.

*Plainview, Minn.*

A total of 9 sets of observations were taken at the Plainview, Minn., plant, the only filter in this investigation that was not housed. Four of the observations were taken when the wind velocity was 2.0 m.p.h. or less. Outside air temperatures varied from 70.2° to 28.5° F.

It was very difficult to obtain draft gage readings for the four observations when the wind velocity was less than

2.0 m.p.h., and impossible when the wind velocity was 2.0 m.p.h. or more. However, actual drafts were measured for two runs and these compared quite well with the computed theoretical drafts. On this basis it seemed that a curve of draft versus air flow comparable to the curve of Figure 2 for Excelsior could be obtained by using the theoretical draft instead of actual draft. Such a curve appeared to approximate the straight line (see Figure 6)

$$h = 0.002\ V.$$

Data from these same runs were also plotted for the relationship between the bulk air flow and the temperature difference between the sewage and the outside air. The straight line through these points was (see Figure 7)

$$V = 0.0867\ D.$$

These data are of a comparative nature and are described in the summary. However, it is evident that a relatively small draft produces high air flows through this open filter and such drafts may be obtained by a stack effect.

For the five runs conducted when the wind velocity was 2.0 m.p.h. or greater, the data obtained was not quantitative, but more of a qualitative nature. The air velocity observations at the underdrain wall ports varied such that the air moved into the filter from the gallery at as high velocities as the air moved out of other wall ports. The data from one of these observations are plotted in Figure 5. All five runs could be plotted in a similar manner, with the arrow indicating the direction of air movement and the numbers indicating air velocities in the underdrain wall ports. The dashed line perpendicular to the wind

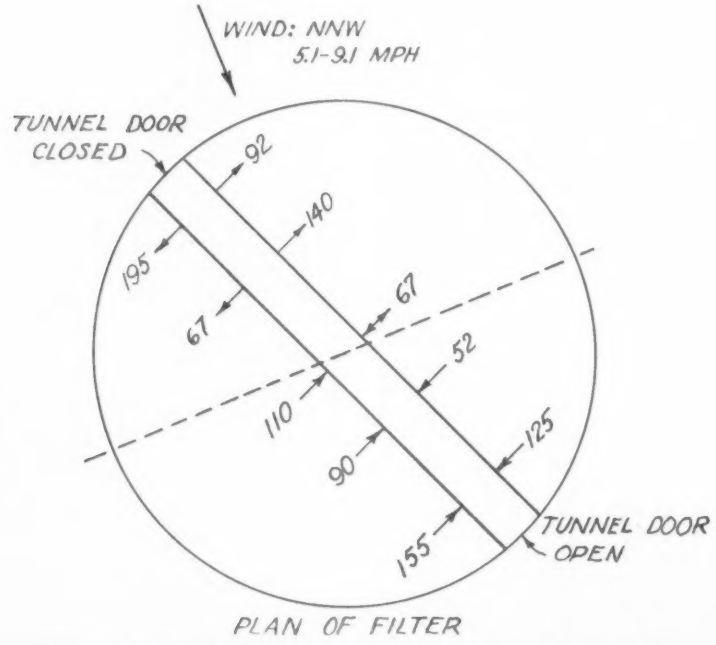


**FIGURE 5.—Example of air circulation in open filter at Plainview, Minn.**

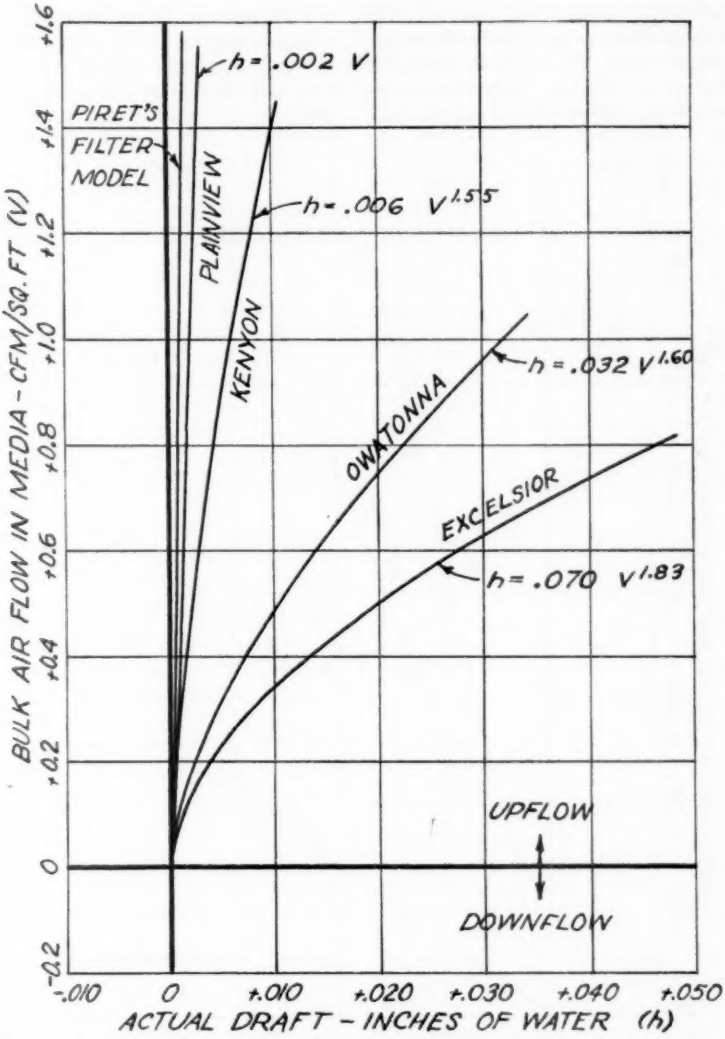


**FIGURE 6.—Relationship between total draft and bulk air flow in trickling filters.**

direction clearly indicates the jump effect of the wind. The upwind half of the filter has air moving from the gallery up through the rock, whereas the downwind section shows the air moving down through the rock into the gallery. In other words, the wind creates a relatively higher pressure on the downwind half of the filter to induce air circulation within the filter media. One of these five runs was conducted with the writer sealed in the tunnel (entrances closed to the outside) and the air velocities observed were only

slightly less than those observed with the tunnel doors open. From these data it seems that the wind is extremely effective in causing ventilation or air circulation within an open filter bed.

### Summary of Experimental Data

The majority of the data were observed for air flow up through the filters, but data secured at the Excelsior, Minn., plant indicate that the mechan-

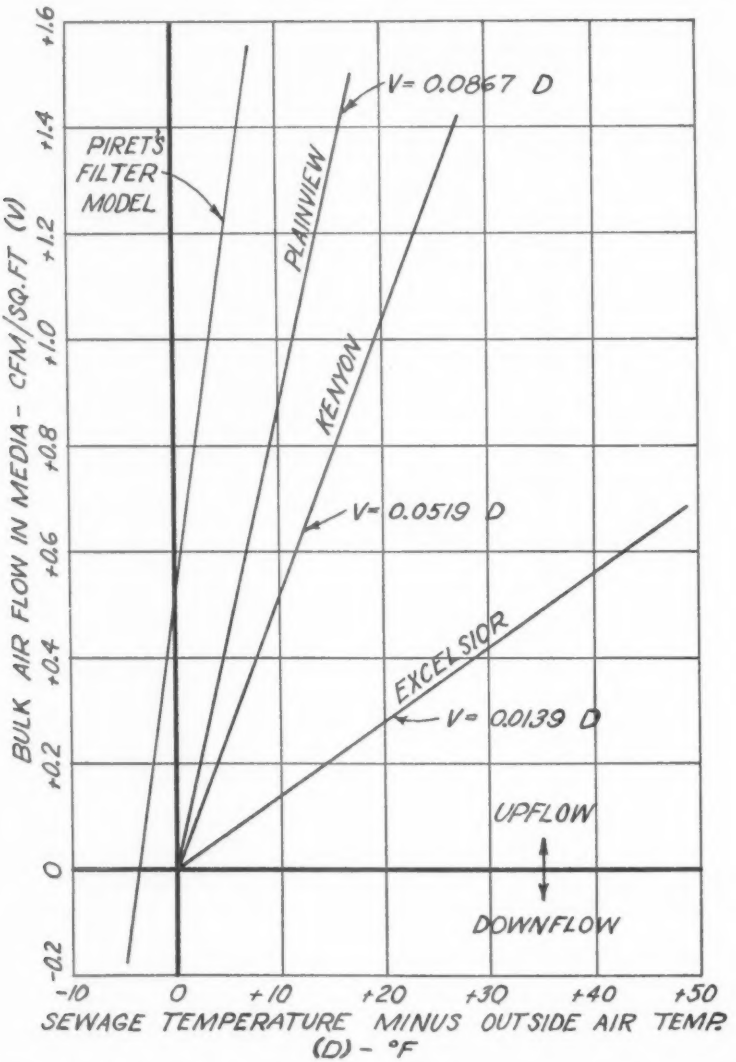


FIGURE 7.—Relationship of difference in temperature between sewage and outside air and the bulk air flow.

ics of air flow down through the filter are quite similar to those shown under upflow conditions. Figure 6 is a summary of the curves of draft *versus* bulk air flow; an additional curve from the work by Piret (3) on a filter model is included. Since Piret's model included resistances comparable to that offered by the media and the top of the underdrain blocks of the Plainview filter, the Plainview curve should (as it does) lie slightly to the right, because it includes the additional resistances of the tunnel and the underdrain system. Therefore, despite the paucity of data from Plainview, the resulting curve seems to be quite accurate. Higher drafts are developed with housed units, but the construction of the housing is such as to limit the air flow below that which is obtained through an open bed with a given draft.

It must be noted that each of these curves applies only to the particular plant from which the data were taken. However, if a filter is similar in construction to one of those described, the air flow characteristics of the two filters should also be the same. The data from Plainview may be applied more readily to other open filters than may the data from the housed filters be used with other housed units.

Figure 7 is a summary of the curves for the bulk air flow *versus* the temperature difference between the sewage and the outside air. Piret's curve does not pass through the origin, due to the relatively high influence of humidity on the very dry air passing through the filter. It is evident that the relative positions of the curves of Figures 6 and 7 are and should be the same for the different plants. For the housed units it is significant that the openings in the top of the housings were the smallest at the Excelsior plant, somewhat larger at Owatonna, and largest at the Kenyon plant. With this in mind, Figures 6 and 7 show better ventilation characteristics with larger openings or less resistance to flow at the top of the housing. Indefinite extrapolation of any of the curves of Figures 6 and 7 is not permissible, because the characteristics of flow may change greatly with higher drafts and the air flow must be at such a rate that the heat exchange between the air and sewage is enough to maintain a draft.

In general, it was found that the effect of the wind was to cause a flow of air up through a housed filter and, due to the jump effect, a general circulation of air is induced in an open bed. The magnitude of the wind effect depends on the local topography and the physical characteristics of the filter. Open filters with walls above the local topography and well exposed to the wind take best advantage of the wind to induce ventilation. Entrances to the filter galleries at the elevation of the underdrains are best to take advantage of the stack effect.

## Annual Variations in Natural Draft

From previous discussion it might be safe to estimate that the approximate bulk air flow requirements might be 0.100 cu. ft. per min. per sq. ft. for an average filter and it seems that housed units present the most critical ventilation problems. By considering the filters at Kenyon, Minn., as having adequate and well-designed gallery and housing openings, the curve on Figure 7 shows that a temperature differential of about 2° F. is necessary to cause this rate of air flow without the influence of wind. To account for the influence of humidity and contingent factors, the minimum temperature difference necessary to assure this rate of flow may be assumed as 5° F.

From a comparison of the sewage temperatures at Owatonna, Minn., for 1950 and the 1950 U. S. Weather Bureau records for Minneapolis, Minn. (these particular records were selected simply because they were at hand), it was found that through the year there

were 70 days when the average air temperature differed from the sewage temperature by 4° F. or less. As the average daily temperature is simply an average of the maximum and minimum temperatures, a daily range of less than 10° F. may be indicative of critical conditions for ventilation. Of the 70 days previously mentioned, only 6 days showed daily temperature ranges of less than 10° F. It was found experimentally that wind velocities over 2.0 m.p.h. were significant in causing ventilation. On the above mentioned 6 days the average surface wind velocity was never less than 5.4 m.p.h., with the minimum value of maximum velocities recorded at 10 m.p.h.

From this study it seems that, due to the diurnal variations of the air temperatures and wind velocities, combinations of small temperature differences between the sewage and the air with low wind velocities are not likely to occur very frequently. Thus, it appears that natural forces may be sufficient to furnish adequate ventilation. However, the geographical location of a filter and local conditions may limit the ventilation, and the length of time a filter may operate without sufficient ventilation is not known.

## Summary and Conclusions

By considering the ultimate B.O.D. reduction in a filter by oxidation and using a safety factor of 20 it was found that comparatively low rates of air flow are required through the media. It appeared from the experimental data that the natural forces inherent with well-designed open and housed filters are most often great enough to provide for these estimated minimum requirements.

It was found that natural drafts occur due to a stack effect and the wind. Drafts due to air density differences were shown to be largely a function of the temperature difference between the sewage and the outside air. The wind was found to cause an upward flow of air in housed filters and a general circulation within open beds. Higher drafts, but lower rates of air flow, generally occur in housed units, due to the additional head losses imposed by the housing.

## Acknowledgment

The writer wishes to acknowledge the assistance and encouragement given by Prof. George J. Schroepfer, of the University of Minnesota, together with the cooperation and help received from the plant operators and others who assisted in the work.

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# HIGH-RATE CHEMICAL AND BIOLOGICAL TREATMENT OF SEWAGE *

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During the past year, the Sanitary Research Laboratory of the University of Florida has been investigating the operating characteristics and efficiencies of a high-rate chemical and biological sewage treatment unit called the "Aero-Accelator," manufactured by Infilco, Inc. As a result of these pilot plant studies, it was found that this unit could be operated so as to produce a stabilized effluent varying in accordance with such factors as cost of operation, condition of the receiving stream, and State Board of Health requirements.

## Description of Unit

The unit investigated is, essentially, a single, circular unit incorporating the principles of primary treatment—with or without chemical coagulation—and secondary treatment. To achieve clarification and stabilization, a slurry circulation type of design is utilized (Figure 1).

The screened raw sewage and compressed air enter at the bottom center of the unit. Here, an intimate combination with the returned, preformed activated floc is achieved by a rotor-disperser, which also serves to disperse the incoming air. Due to the lift effect of the air, the sewage-air-floc mixture is directed upward in the central draft tube of the unit. At the upper surface of the draft tube, the mixture flows over an adjustable concentric ring and down into the "return flow" zone. This adjustable ring can be set to provide desired recirculation ratios. In the return flow zone, the clarified liquor flows upward from the mixed liquor, and the active floc moves down. This entire floc is then returned to meet the incoming sewage. The effluent is removed by a peripheral weir. A portion of the return flow zone is used as a concentrator for the collection and removal of excess sludge. Removal of the concentrated sludge is regulated by an automatic blow-off arrangement operated on an adjustable time cycle.

If chemicals are to be used, they are added, by gravity, directly to the mixing section beneath the rotor. This achieves rapid and thorough mixing as soon as the sewage enters the unit.

## Operational Data

This type of unit can be utilized in several ways to achieve clarification and stabilization of sewage. It can be operated as:

1. An "activated slurry" process unit.
2. An "activated slurry" process unit plus the addition of chemicals (biochemical process).
3. A treatment process unit using calcium carbonate plus small amounts of air (modified Daytona Beach process).
4. A chemical treatment process, with slight mechanical modifications (Daytona Beach process).

Design criterion for the 2,300-gal. pilot plant model utilized for these in-

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns; St. Paul, Minn., Oct. 8–11, 1951.

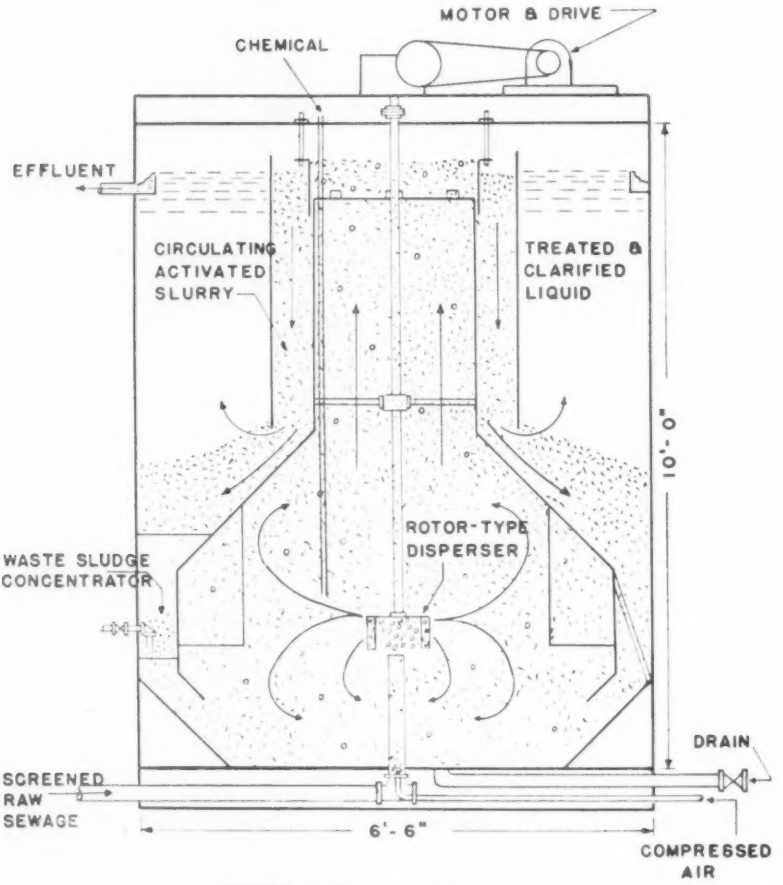


**FIGURE 1.—Section of pilot plant unit.**

vestigations is a 3.8-hr. detention time at 10-g.p.m. flow rate. It is noteworthy that this is the entire time of treatment from raw sewage to clarified effluent.

This paper is concerned with results obtained while operating in the following manners:

1. As an "activated slurry" type of treatment unit.
2. As an "activated slurry" type of treatment unit with the addition of a chemical (calcium carbonate sludge from a municipal water softening plant).
3. As a treatment unit using calcium carbonate sludge plus small quantities of air.

The term "calcium carbonate sludge" as used throughout this paper signifies the waste sludge from a municipal water softening plant. It is composed, in the main, of calcium carbonate (about 91 per cent), and magnesium hydroxide (about 5 per

cent). The detailed analysis of this sludge is given in Table I. Operation of a full-scale unit as a chemical treatment plant without air has been previously reported (1).

The sewage arriving at the Sanitary Research Laboratory pilot plant is, in the main, a domestic sewage from student villages on the campus of the University. It is a somewhat weak sewage, averaging about 125 p.p.m. B.O.D. on a 24-hr. composite sample. The peak strength is about 250 p.p.m. B.O.D., whereas the night sewage falls to about 10 p.p.m. B.O.D. Due to the short distances involved, it is almost always a fresh sewage, reaching the treatment plant within 45 min.

Sewage flow entering the plant is kept constant at 60 g.p.m. by means of an overflow diversion at the head of the plant. During the hours of low flow from the villages, the plant influent is kept constant by the inclusion of a portion of the raw sewage going to the main campus treatment plant.

Samples for all analyses of the raw sewage and the effluent were composited over a 24-hr. period. An automatic sampler transferred small portions every 5 min. into a jug kept in a refrigerated compartment. All analyses were performed according to "Standard Methods" (2).

## Experimental Data

### *Series 1—Activated Slurry Process*

Operation of the pilot unit as an "activated slurry" process unit was of an exploratory nature. The results obtained have been gathered over a short interval of time and although the data are insufficient for over-all conclusions, it was shown that a biological floc could be produced. This floc was a typical activated sludge type, as shown by physical appearance, microscopic examinations, and degree of purification. It was demonstrated, therefore, that the unit can be operated utilizing an "activated slurry" process.

**TABLE I.—Water Plant Sludge Analysis[1,2]**

| Hypothetical Combination | % |
|---|---|
| Organic matter and water of hydration | 0.74 |
| Silica, $SiO_2$ | 0.46 |
| Iron hydroxide, $Fe(OH)_3$ | 0.25 |
| Aluminum sulfate, $Al_2(SO_4)_3$ | 0.27 |
| Aluminum hydroxide, $Al(OH)_3$ | 2.08 |
| Calcium carbonate, $CaCO_3$ | 91.00 |
| Magnesium hydroxide, $Mg(OH)_2$ | 5.20 |
| | 100.00 |

[1] Results based on sample dried at 110° C.
[2] Courtesy of Black Laboratories, Inc., Gainesville, Fla.

### *Series 2—Activated Slurry Plus Calcium Carbonate (Biochemical Process)*

Over a two-month period, the pilot plant unit was operated as an "activated slurry" type unit with the addition of calcium carbonate sludge from a water softening plant. The primary objectives of this series of experiments were to determine the effects of the calcium carbonate and the optimum doses to be employed. The flow was kept constant at 10 g.p.m. (design rate) giving a 3.8-hr. detention time; air input was 4 c.f.m. during the day and 2 c.f.m. during the night. The duration of the run was 44 days.

Three different doses of calcium carbonate sludge were considered to give a reasonable preliminary range; 200, 100, and 50 p.p.m., were added in three series. The results of this phase of investigation are given in Table II.

**TABLE II.—"Activated Slurry" plus Calcium Carbonate: Summary of Series 2 (Average Values)**

| $CaCO_3$ (p.p.m.) | Effluent (p.p.m.) | | Removal (%) | | Air Input (cu. ft./gal.) |
|---|---|---|---|---|---|
| | B.O.D. | Susp. Sol. | B.O.D. | Susp. Sol. | |
| 200 | 10 | 18 | 91.1 | 95.3 | 0.28 |
| 100 | 9 | 12 | 95.2 | 94.6 | 0.30 |
| 50 | 17 | 11 | 86.9 | 92.4 | 0.30 |

The addition of calcium carbonate in this study indicated several possible operating advantages. First, operation was greatly stabilized. It appeared that the calcium carbonate slurry had a weighting effect on the activated floc, which produced more rapid and more uniform settling of the sludge. Second, when calcium carbonate was added air requirements were somewhat lower than with conventional methods for an equal degree of treatment. In the pilot unit a typical activated sludge was present with an air input of approximately 0.3 cu. ft. of air per gallon of sewage treated, whereas 0.5 to 1.5 cu. ft. of air per gallon are required for activated sludge when carbonate is not added.

*Series 3—Calcium Carbonate Plus Low Air Input*

The distinction between this series and tests previously discussed under Series 2 above, lies in the amount of air input. For the previous series, the air input quantity was chosen as approaching that required by the conventional activated sludge process. For this series, the quantity of air input was determined as that amount necessary to keep the dissolved oxygen (D.O.) content of the mixed liquor section at a predetermined level. It was decided to keep the D.O. at 1 p.p.m. with the thought of not attempting to build an activated sludge, but merely to furnish enough air to keep the mixture in an aerobic condition. This value of 1 p.p.m. D.O., it was felt, would meet this requirement and yet not make operational control too critical, as might a lower value.

Two phases were investigated under the above conditions. The first was to determine, more exactly, what the optimum calcium carbonate dose was at the design rate of flow with a 3.8-hr. detention time. The results of this series are given in Table III. The duration of the run was 64 days.

**TABLE III.—Efficiencies at Various Detention Times (Calcium Carbonate Plus Low Air Input): Summary of Series 3A (Average Values)**

| $CaCO_3$ (p.p.m.) | Effluent (p.p.m.) | | Removal (%) | | Air Input (cu. ft./gal.) |
|---|---|---|---|---|---|
| | B.O.D. | Susp. Sol. | B.O.D. | Susp. Sol. | |
| 25 | 45 | 53 | 70.4 | 69.6 | 0.16 |
| 50 | 50 | 63 | 74.6 | 66.5 | 0.19 |
| 75 | 28 | 30[1] | 82.1 | 79.9[2] | 0.13 |
| 100 | 32 | 45 | 74.3 | 64.8 | 0.11 |

[1] Based on 6 days sampling only.
[2] Based on 8 days sampling only.

The outstanding feature of this run was the fact that a type of activated sludge was produced with the low quantities of air supplied. With an air input of less than 0.2 cu. ft. per gallon of sewage (0.11 to 0.19 cu. ft. per gal.), a biological floc was constantly maintained in the unit. That this floc was biological in nature was shown by the degree of B.O.D. removals achieved, and also by microscopic examinations of the mixed liquor conducted at various times.

The microbiology of the mixed liquor was such that the term "atypical" activated sludge should be applied in this situation. A "normal" or "typical" activated sludge microscopically reveals a balance of certain organisms (for example, protozoans as peritrichs, holotrichs, hypotrichs; and gelatinous zoogleal masses containing bacteria. The mixed liquor developed during this series revealed that some of the usual activated sludge organisms were present, but not all. For example, during one series holotrichs and hypotrichs were commonly found, as well as the typical gelatinous masses, but peritrichs were absent. Generally, it was found that peritrichs were present and holotrichs and hypotrichs were absent. This sludge appeared, usually, to contain smaller numbers of metazoans, particularly rotifiers, than activated sludge. The picture would change in

TABLE IV.—Efficiencies at Various Detention Times (Calcium Carbonate Plus Low Air Input): Summary of Series 3B (Average Values)

| Flow (g.p.m.) | Det. (hr.) | Effluent (p.p.m.) | | Removal (%) | | Air (cu. ft./gal.) |
|---|---|---|---|---|---|---|
| | | B.O.D. | Susp. Sol. | B.O.D. | Susp. Sol. | |
| 10[1] | 3.8 | 28 | 30 | 82.1 | 79.9 | 0.13 |
| 15 | 2.9[2] | 28 | 45 | 75.2 | 66.6 | 0.12 |
| 18 | 2.5[2] | 35 | 21 | 65.9 | 77.1 | 0.16 |
| 20.7 | 2.1[2] | 22 | 24 | 81.5 | 75.6 | 0.10 |

[1] Results from Series 3A.
[2] Variation in detention time resulted from a change in unit capacity.

relative numbers and types of organisms, but the floc always remained biologically active.

In the second phase of this series, with the optimum dose (75 p.p.m.) of calcium carbonate added and sufficient air to maintain 1 p.p.m. D.O. in the mixed liquor, the flow rates were increased above design values. Operating criteria and efficiencies were then determined. During this period the flow was increased to 15, 18, and 20.7 g.p.m., the latter representing a detention time of 2.13 hr. Results of this phase of operation are summarized in Table IV. The run duration was 45 days.

It was found that with the conditions present at this pilot plant, the unit could handle more than twice the design capacity (duration of run approximately 2 months) and produce a good quality effluent. This was accomplished with slightly greater than 2-hr. detention time for the entire treatment process—from raw sewage to final effluent.

## General Discussion

The following observations are pertinent to all investigations discussed in this paper. All final effluent samples were unsettled samples, collected from the effluent discharge line.

It must be realized that operational control of this unit was performed by a graduate student. This means that control was limited during certain periods of the day and it is felt that better efficiencies could be attained with closer control. During the last run, the student had more time available; consequently, better results were obtained, with fewer operational problems.

The pilot unit did not, however, present any unusual problems during these investigations. If operated as a biological treatment unit, it requires the usual plant control measures (as in activated sludge)—for example, dissolved oxygen and suspended solids content of the mixed liquor, settling tests, wasting of sludge, etc. Daily microscopic examinations would be helpful.

Wasting of sludge from this type of unit is determined by the concentration of solids in the mixed liquor and by the slurry level in the settling zone of the unit. There is a zone in the unit within which it is desirable to keep this level. For the 10-ft. high pilot plant unit herein reported, this zone was 9 in. high, starting 4.5 ft. from the bottom. The sludge level, therefore, is maintained at, or slightly below, the outer draft tube.

It was found during these investigations that the unit was well able to cope with a type of shock loading. The sewage entering the pilot plant is extremely weak, with a B.O.D. of about 10 p.p.m., for periods of about 6-hr. duration during the night. Within 2 hr., in the early morning, the B.O.D. will increase to 250 p.p.m. A low strength sewage for long time intervals followed by a sudden large increase in strength is a burden on an activated sludge type plant and it is difficult to keep the floc in condition during the weak periods. The pilot unit was apparently able to respond to this daily schedule with no detrimental effects.

Operational economies have not been investigated on an actual cost basis, as they will vary according to time and place. However, several factors remain constant and these should be borne in mind when evaluating this type of unit. First, a single unit is employed instead of multiple units. This means that the one unit can eliminate the need for primary sedimentation and secondary settling tanks, because it performs their functions as well as that of secondary treatment. Second, the air requirements are apparently much lower for corresponding removals than in a conventional activated sludge process. This means a saving on one of the major items of cost in this type of treatment. Third, the problems of diffuser clogging are eliminated, as no diffusers are employed. Fourth, the cost of the calcium carbonate sludge should involve only handling, inasmuch as the water softening plant must dispose of its sludge. Fifth, operating personnel requirements may be somewhat less than with conventional activated sludge plants.

Several factors in operation should be investigated further, and will be in the future. Some of these are (a) optimum suspended solids concentration, (b) optimum rotor speed, (c) recirculation ratios, and (d) a more exact program of sludge removal from the unit. It is felt that greater knowledge of these points will aid in more efficient operation.

## Summary

A pilot plant model of a single-unit sewage treatment plant has been subjected to a series of investigations at the Sanitary Research Laboratory of the University of Florida. Although all factors have not been integrated and evaluated, it has been found that:

1. Operation as an "activated slurry" type process of sewage treatment is possible. Additional operational data are to be gathered.

2. Operation as a "biochemical" process is also feasible. When calcium carbonate is added to an activated sludge, as much as 95 per cent of the B.O.D. of the sewage can be removed with 0.30 cu. ft. of air per gallon of sewage. The calcium carbonate should be added in a ratio of about 1 part of calcium carbonate ($CaCO_3$) to 1 part of suspended solids (for example, a sewage with 200 p.p.m. suspended solids would require about 1,700 lb. of calcium carbonate per million gallons of sewage.

3. Operation as a "modified Daytona Beach process" (calcium carbonate plus low air input) resulted in a form of biological treatment wherein an atypical activated sludge floc was formed. Using 0.13 cu. ft. of air per gallon of sewage, 82 per cent of the B.O.D. could be removed at the design rate of flow. At more than twice the design rate, 81 per cent of the B.O.D. was removed using 0.10 cu. ft. of air per gallon of sewage.

4. When operating as a biological treatment unit, frequent microscopic examination of the mixed liquor appears to be a useful additional tool for the control of the unit's performance.

It should be mentioned that the digestion of sludge from a calcium carbonate process in this unit has been investigated at this laboratory. Digestion of such sludge apparently presents no unusual problems.

## Acknowledgments

The authors wish to express acknowledgment to Infilco, Inc., sponsors of this project; to Professor W. T. Calaway for his assistance with the microbiology, as well as other phases of the project; to Professors E. B. Phelps and J. E. Kiker, Jr., for their advice and assistance; and to D. Busciglio for his assistance in the control and analytical phases of this project.

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## DISCUSSION

By A. J. Fischer

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Professor Jaffe's investigations of the Aero-Accelator are interesting in that they show that under certain conditions the unit is capable of producing high quality effluents. These conditions are that (a) the sewage be fresh, possibly containing D.O.; (b) the sewage be weak, averaging 125 p.p.m. B.O.D. or less; (c) the flow be constant; (d) a controlled amount of $CaCO_3$ be added to the sewage; and (e) about 0.3 cu. ft. of air be added per gallon of sewage.

Considerable work is still to be done before the method described may be adapted and proper conditions established for the treatment of average or high strength sewages or for treatment without the addition of $CaCO_3$.

It is difficult to evaluate the beneficial effects claimed for $CaCO_3$ addition as no results are given on runs with aeration alone. Nor can any valid comparison be made with other types of activation units for the same reason.

It is reasonable to expect that the $CaCO_3$ added has a favorable weighting effect and that its absence at low detention and low air addition may seriously alter the operating results presented. Eidsness (1), in describing tests at three locations on a pilot plant the same as or similar to that used by Jaffe, makes the interesting observations that: (a) sludge bulking occurred at low air quantities when $CaCO_3$ was not added, but never occurred when present; (b) with average or strong sewages considerably more air had to be added than when a weak sewage was treated; and (c) periodic peak loads caused difficulties. These observations appear to be entirely reasonable and will undoubtedly be confirmed by the continuing work of Jaffe.

The observation by the author that the unit was well able to cope with "a type of shock loading" should not be misinterpreted. The fact that he showed that it was possible for his plant to handle a sudden increase in B.O.D. to 250 p.p.m. from a 6-hr. low of 10 p.p.m. means little. Its capability for handling a sustained load of 250 p.p.m. or sudden peaks above this figure would be more significant. Most small plants receive extremely weak sewage during the early morning hours and should be designed on the basis of the B.O.D. of the 18-hr. flow, rather than on the 24-hr. average. This is especially true of small activated sludge installations, even where liberal aeration tank capacity is provided. Where high-rate (that is, short period) aeration is practiced, conditions should be much more critical, as the activated sludge does not get the chance to recuperate as it does with long detention periods. In this respect, it would be of interest to know what the effluent condition was during the day and from day to day, rather than for long-time averages.

It is presumed that the Aero-Accelator should work satisfactorily as an activation unit, provided a proper balance is maintained among sewage strength, detention, rate of sludge recirculation, and air quantity. Many small combination type units, wherein

aeration and sedimentation are carried out in a single tank, are in commercial operation. A large number of these dispense with pre-sedimentation. Work at Chicago and elsewhere has demonstrated that with weak sewages good activation may be obtained with relatively short detentions and low air consumption. Likewise, combination mechanical-air diffusion types of aeration systems have demonstrated economies in air consumption. The addition of chemicals and weighting agents for reducing aeration time and air quantities have been used by Guggenheim in this country and by Zigerli abroad.

Results on sludge digestion experiments being carried on by the author should be interesting. In a number of small plants here and in Canada it was found that although activated sludge alone will digest readily, very large tank volumes are required because the sludge does not concentrate. As a result the supernatant liquor usually has about the same solids content as the incoming feed. It may possibly be that the addition of $CaCO_3$ may alter this condition. At the same time, however, the $CaCO_3$ will add to the bulk of sludge that must be disposed of. Based on results reported at Grand Rapids, Mich., $CaCO_3$ should not adversely affect digestion if the proportion of $CaCO_3$ to sewage sludge solids is 1:1 or less.

Professor Jaffe and his co-workers are to be commended for their investigations made to date. It is hoped that they may be able to continue their work so that the many variables affecting their results may be more closely defined and a proper evaluation of the limitations and economics of the Aero-Accelator made possible.

### Reference

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## THREE NORTH CAROLINA UNIVERSITIES LAUNCH ANNUAL SERIES OF WASTES DISPOSAL CONFERENCES

Under the joint sponsorship of Duke University, North Carolina State College, and the University of North Carolina, a series of annual Municipal and Industrial Waste Conferences was recently established. The first conference is to be held March 13–14 at North Carolina State College for the purpose of promoting cooperative solutions of municipal and industrial waste disposal problems.

The conference program on "Clean Streams in Southern Economy" will be led by outstanding figures in the field of industrial and municipal waste control. Workshop discussions of current waste disposal problems will feature those arising from textile, synthetic fiber, and paper industries. Tentative plans have been made to publish the conference proceedings.

The annual conferences will be integrated with the short schools for sewage and water plant operators which the three institutions conduct each year for the North Carolina Sewage Works Association and the North Carolina Section, AWWA.

Information about the March 13–14 meeting, as well as other Conference matters, may be obtained from Dr. Nelson Nemerow, Civil Engineering Dept., North Carolina State College, Raleigh, N. C.

# A METHOD OF ESTIMATING SULFIDES IN WATERS

By J. E. Houlihan and P. E. L. Farina

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When the dissolved oxygen in a polluted watercourse has fallen to zero and this condition has persisted for some time, it may well happen that hydrogen sulfide is liberated upon adding acid to the Winkler sample. It was thought that some measure of the sulfide content could be obtained by the measurement of absorption of iodine, particularly since the iodine solution could conveniently be formed *in situ* by running N/80 potassium permanganate solution into the Winkler treated sample. It was necessary to make allowance for substances other than sulfides which might react with iodine and a blank was carried out on a portion of the sample which had been freed from hydrogen sulfide by gassing it away with nitrogen from an acid solution.

Many iodiometric methods for the estimation of sulfides are given in the literature. Although they vary in detail, they are usually based on one of two main procedures: (a) by driving hydrogen sulfide from an acid solution in a stream of nitrogen, with re-absorption in a suitable solution (usually cadmium or zinc acetate), in which it can be determined by iodine treatment; and (b) by loss of iodine demand upon acidification and gassing off the hydrogen sulfide.

The former method is generally held to give a high degree of accuracy and is the basis of the titration method described in "Standard Methods" (1). Many varied methods are summarized by Mahlie (2), but it was the work of Pomeroy (3)(4) upon which the A.P.H.A. method was based.

In general, methods involving absorption in cadmium or zinc salts are held to be capable of a high degree of accuracy, whereas those involving loss of iodine demand are offered as having only an approximate value as a rough field test, or even of no value at all. Nevertheless, it was thought that a method which could give by one routine operation a measure of either dissolved oxygen or total sulfides (each in the absence of the other) would be of too great a value to abandon without further investigation. Efforts were accordingly concentrated on improving the accuracy of a technique based on loss of iodine demand, particularly since the shorter methods of estimation of sulfides, such as the methylene blue method, were not, in the writers' experience, of a sufficiently high order of accuracy.

In developing a suitable technique, many problems had to be resolved: air had to be excluded at all stages to prevent oxidation, gaseous hydrogen sulfide must not escape, particularly in the transfer of a sample; and the attenuated and doubtful titration end points common with weak solutions had to be made sharp and repeatable. Even commercial nitrogen gas could not be used unless the small oxygen impurity were scrubbed out. The technique was built up step by step into a reliable routine.

## Method

### *1. Reagents*

1.1. Manganous chloride solution. Dissolve 800 g. of $Mn\ Cl_2 \cdot 4H_2O$ in distilled water and make up to 1 l.

1.2. Alkaline iodide sodium azide. Prepare a solution containing 300 g.

NaOH, 150 g. KI, and 10 g. Na $N_3$ per liter.

1.3. Hydrochloric acid, concd.

1.4. Iodine solution, N/80.

1.5. Sodium thiosulfate solution, N/80.

1.6. Starch solution.

All reagents are of "Analar" quality.

*2. Sampling*

A standard dissolved oxygen (D.O.) depth sampling apparatus is used containing a bottle of approximately 500-ml. capacity. An additional quantity of sample not less than 500 ml. is required for the determination of the blank. This portion, taken from the container, should be set aside in a stoppered bottle completely filled with the liquid and kept in a cool dark place until required.

*3. Treatment with Winkler Reagents*

The D.O. sample is treated with 1 ml. of solution 1.1. and 2 ml. of solution 1.2., either immediately after withdrawal from the river or upon receipt at the laboratory (usually within 10 min.) At the end of 10 min. the sample is again thoroughly shaken and allowed to re-settle for a similar period so that there is a minimum of 20 min. before analysis commences. During this period the bottle should be kept in a dark cool place.

*4. Procedure*

A 1-l. conical flask is filled with nitrogen, preferably by downward displacement, and 10 ml. of iodine solution (or more if the sulfide content is expected to require it) is accurately pipetted into the flask. At this stage it is convenient to stopper the flask with a bung in which there is a hole to take the stem of a pipette and which can then be closed with a smaller stopper. 7 ml. of hydrochloric acid is carefully poured into the Winkler treated sample, the double stopper device is quickly fitted into the bottle and then inverted and fitted into the flask, so that the contents of the bottle empty into the flask. The apparatus is now inverted two or three times so that the liquid is well-mixed by transfer alternately between bottle and flask. The sample is allowed to stand on the bench for 10 to 15 min. and is finally titrated with N/80 thiosulfate. The operation is shown diagrammatically in Figure 1.

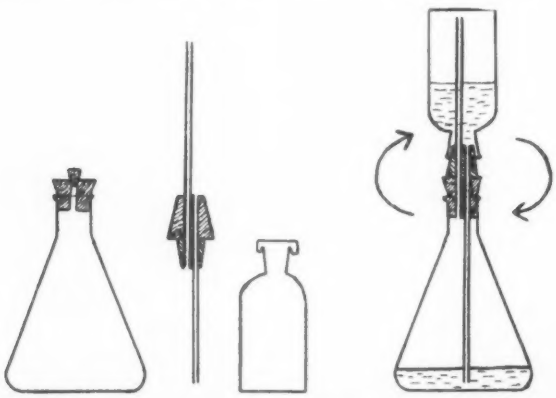

**FIGURE 1.—Double stopper device for air exclusion, made with waxed corks.**

*Iodine Demand of Blank*

500 ml. of the reserved sample is measured into a 1-l. conical flask, aeration being avoided as much as possible. 7 ml. of hydrochloric acid is added and the flask is closed with a two-way hole bung carrying suitable gas bubbling connections. Oxygen-free nitrogen is passed in vigorously until hydrogen sulfide ceases to be evolved, as indicated by a lead-paper test. 2 ml. of alkaline iodide reagent is mixed in and the liquid is treated alongside the main sample with 10 ml. of N/80 iodine and left 10 to 15 min. before titration.

*Calculation*

1 ml. of N/80 iodine is equivalent to 0.2 mg. of S″. Hence, for exactly 500-ml. samples (after allowing for the initial 3 ml. of reagents added), and if $x$ equals the ml. of iodine solution absorbed by the sample and $y$ equals the ml. of iodine solution absorbed by the blank,

$$0.4\ (x\text{-}y) = \text{S}''(\text{p.p.m.})$$

## Alternative Method for Total Iodine Demand

Although somewhat less accurate, an alternative procedure for total iodine demand is simpler and is more useful when dealing with an unknown range of sulfide concentration, more particularly when it is uncertain if dissolved oxygen or sulfide is present. When the sulfide content is less than 1 p.p.m. the loss of accuracy is negligible.

The sample, previously treated with Winkler reagents, is acidified in the usual way and 20 to 30 ml. is poured quietly into a smaller stoppered bottle containing a little starch solution; this will indicate the presence or absence of oxygen. If oxygen is absent, sufficient iodine solution is measured into the main sample to provide an excess. The remaining portion is also treated either by running in a little of the measured iodine solution or by adding enough of the treated main sample to give a good blue color with the starch solution. It is important that during these operations the stoppers should be removed for the minimum possible periods. After standing for the usual length of time, the main sample is transferred to a flask and titrated almost to completion; the contents of the smaller bottle are added and the titration completed.

*Notes*

1. N/80 potassium permanganate solution may be substituted for the N/80 iodine solution, as it is immediately converted into its equivalent of iodine by the hydriodic acid present in the acid solution. No untoward side effects have been noticed.

2. The preparation of the sample for titration (for example, the potassium iodide concentration, time of standing on the bench, end point, etc.) should be carefully standardized. It is even desirable to standardize the thiosulfate solution with a solution equal in volume and in concentration of reagents to that of the test solutions. Titration can be carried out to a standard shade of blue, but it has been found better to titrate to the first discharge of the blue color.

3. Rubber should not be exposed to free hydrogen sulfide: all stoppers should be of glass or waxed cork.

## Choice of Method for Comparison

Having developed a routine technique, it became necessary to confirm how far it was accurate as a measure of sulfide content. It was decided to compare it with a method involving liberation of hydrogen sulfide with reabsorption in a suitable solution and subsequent iodine titration. The method chosen was based on that described as the titration method in "Standard Methods" (1). It was at this stage that difficulties were en-

countered and the first comparisons were poor.

General experience is that sulfides are difficult to determine accurately. In addition to the precautions taken in building up the technique against oxidation, loss of hydrogen sulfide gas, and weak end points, there was the difficulty that sulfides do not provide stable or reliable standard solutions and it became necessary to devise a method of dividing a sample into two portions having exactly the same sulfide concentration. Further, the presence of a small amount of residual oxygen in nitrogen gas is sufficient to affect comparisons, even though the greater part of the hydrogen sulfide is driven over in the first few minutes. As with the routine technique, the method adopted for testing it was built up by stages, eliminating sources of error one by one.

### Procedure for Comparison

The sample is taken in a Winchester pint bottle, filled to the top, and stoppered to exclude air. The bottle is well shaken to ensure uniform dispersion of the solids and, by means of a suitable connection, the sample is forced over by nitrogen gas into two 500-ml. bottles previously filled with the gas. This process is done rapidly with continued agitation to prevent any settlement of suspended solids, and the bottles are stoppered quickly. One of the two bottles is set aside to be treated by the routine technique, previously described, using the air-excluding device. The second bottle is treated with 7 ml. of hydrochloric acid poured gently as a layer at the bottom by means of a long-stemmed narrow-bore funnel. The bottle is leveled off to a known volume by replacing the stopper momentarily (care being taken to preserve the layers) and then is introduced into the train already swept with nitrogen gas. The train consists of a cylinder of nitrogen gas followed by two Dreschel bottles containing alkaline pyrogallol (10 per cent in 20 per cent NaOH solution) to remove oxygen; a further Dreschel bottle holding glass wool moistened with 25 per cent sulfuric acid; then the sample followed by an empty 500-ml. bottle; and, finally, two Dreschel bottles each holding 50 ml. of a 2 per cent cadmium acetate solution acidified with acetic acid equal to 0.1 per cent. The sample is inserted in the train and all joints are confirmed to be gastight. The gas is set running and when the sample starts to siphon, the bottle is swirled round to mix in the acid. The tubing has been adjusted so that when half

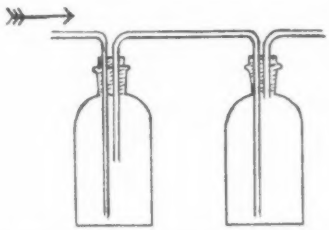

**FIGURE 2.—Arrangement of tubing to introduce full sample bottle into train without loss of $H_2S$ and to divide the sample between the two bottles by nitrogen gas.**

the contents of the sample bottle are driven into the second bottle the siphon breaks and gas bubbles through both half-filled bottles (Figure 2). The gas is left bubbling fairly vigorously at a rate not less than 1 cu. ft. per hr. At the end of 1 hr. a moistened lead acetate paper is inserted between the sample and the absorbent to confirm that all hydrogen sulfide has been driven over. The Dreschel bottles containing the cadmium acetate solution are detached from the train and treated with a measured excess of N/80 iodine solution, all but a small reserve being run into the first bottle. After thorough mixing, 10 ml. of concentrated

hydrochloric acid is added to each bottle by way of the inlet tube. When the reactions are completed, as shown by the disappearance of the precipitate, the contents of both bottles are washed into a flask, 1 ml. of 15 per cent potassium iodide solution is added, and the whole is titrated with thiosulfate solution.

The sample remaining in the two bottles in the train is treated with 2 ml. of alkaline iodide Winkler reagent and then with 10 ml. iodine solution to act as the blank for the portion treated by the direct technique.

*Notes*

1. It is important that a comparison of the two methods should be made on two portions obtained by dividing a single sample with due care; duplicate samples taken under similar conditions are not certain to give sufficiently close agreement.

2. A blank should be run using oxygen-free distilled water: reagents can give small absorptions.

3. Nitrogen gas must be free from oxygen and is much to be preferred to carbon dioxide, which may give a high blank result and which must be specially freed from oxygen.

4. Iodine titrations of all samples, blanks, and standardizations should be made in the presence of a minimum concentration of hydriodic acid (added as potassium iodide to the solution). The amount of potassium iodide introduced by the alkaline iodide Winkler reagent gives about 460 p.p.m. of hydrogen iodide, which is above the concentration required. It is a matter of practical experience that the presence of hydrogen iodide speeds up the reaction to a sharp end point and that in the virtual absence of hydrogen iodide the reaction does not reach finality until the re-appearing color has been discharged repeatedly over a long period of time.

**TABLE I.—Comparison of Methods for Determination of Sulfides (in P.P.M.)**

| Det. No. | Direct Technique | Absorption Method |
|---|---|---|
| 1 | 26.80 | 26.14 |
| 2 | 8.09 | 7.76 |
| 3 | 6.91 | 7.12 |
| 4 | 19.05 | 19.35 |
| 5 | 0.32 | 0.33 |
| 6 | 4.50 | 4.50 |
| 7 | 11.14 | 11.54 |
| 8 | 0.68 | 0.82 |
| 9 | 1.35 | 1.46 |
| Blanks | 0.02, 0.00 | 0.06, 0.06 |

## Results and Discussion

Table I shows the results of comparisons made on samples of varying sulfide contents. Most of the samples consisted of river water, to which hydrogen sulfide had been added and then set aside for several days to stabilize.

The results indicate a very satisfactory degree of agreement, particularly in the range in which sulfides have been found in polluted river water; that is, up to a (rarely attained) maximum of 7 p.p.m. Pomeroy (3) found that sulfides estimated by absorption in zinc acetate were constantly lower in amount than those determined by the loss of iodine demand on acidification and bubbling with nitrogen. He assessed his results on theoretical grounds by a consideration of the behavior of the possible constituents and of the possible sources of error. Pomeroy rejected the method based on loss of iodine demand as being too much subject to serious errors although he accepted the method involving absorption in zinc acetate as being quite accurate under ordinary conditions. Pomeroy's experiments were made with sewages and effluents, liquors which will have greater natural iodine demands than river waters. He also stated that it was impossible to secure

sharp and stable end points in the presence of sewage solids and that errors due to this cause were serious at low sulfide concentrations. It is the writers' experience that river water solids could cause the same errors in a lesser degree, but that the presence of hydrogen iodide ensures a reasonably sharp and definite non-returning end point, even with rather dirty samples. Under such conditions, end points should be definite within two drops; in any event, the sample and the blank are paired to matched end points. Under experimental conditions, using 500-ml. samples and N/80 solutions, 0.1 ml. represents 0.04 p.p.m. of S″.

The high sensitivity of the method was emphasized during the first few comparisons, when the figures obtained by the absorption method were consistently lower than those given by the direct method. The difference was found to be attributable to the presence of oxygen as an impurity in the nitrogen gas. Although the greater part of the hydrogen sulfide is driven over in the first few minutes, the total amount of oxygen in commercial nitrogen may be sufficient to oxidize more than 100 times the sulfide content to be estimated.

A further indication of the need for care is given by the consideration that 1.0 ml. of N/80 iodine solution is equivalent to 0.14 ml. of hydrogen sulfide gas, an amount which could easily be lost in dividing or transferring the sample unless specially guarded against. This would represent 0.4 p.p.m. of S″, which is about 10 per cent of the amount met with in the more highly polluted samples.

## Possible Errors

Methods employing loss of iodine demand have been criticized on account of errors arising from: (a) bad end points, (b) interference from metallic salts, (c) interference from nitrites, and (d) interference by iodine-consuming sulfur acids. It should be remembered that all of these criticisms have been passed on iodine demand methods applied to sewage and similar liquors. In the less impure and more dilute medium of river water the influence of interfering substances should be more restricted.

### *End Points*

River water would naturally give a clearer liquid for matching end points, but in any case the practice of maintaining the hydrogen iodide level for all titrations ensures sharper and repeatable end points.

### *Metallic Salts*

In a normal watercourse which is not heavily polluted by large quantities of particular industrial wastes, the only metal which needs consideration is iron. Although ferrous iron will absorb iodine, a similar absorption will occur in the blank, because it is treated in a similar manner, hence any effect due to the metal is nullified.

### *Nitrites*

The Winkler reagents contain sodium azide, which in acid solution, as hydrazoic acid, destroys any nitrite. Normally, sulfides and nitrites are unlikely to co-exist for any length of time in a water. Old azide solution can liberate small amounts of iodine from hydriodic acid, but the effect is canceled out by the same treatment given to the blank.

### *Salts of Iodine-Consuming Sulfur Acids*

The interfering salts of iodine-consuming sulfur acids include sulfites, thiosulfates, etc., all of which absorb iodine in acid solution. Normally salts of these acids do not occur in a river unless it is heavily polluted industrially. There is, however, strong presumptive evidence that thiosulfates are formed as a result of oxidation of sulfides in the slightly alkaline condi-

TABLE II.—Interference from $SO_2$ from Sulfur Acids (in P.P.M. of S″)

| Run No. | From Sulfides, Absorption Method | By $SO_2$ in Filtrate | By $SO_2$ in $H_2O_2$ | Total S″ as $SO_2$ |
|---|---|---|---|---|
| 1 | 6.35 | 0.08 | 0.03 | 0.11 |
| 2 | 7.00 | 0.04 | 0.04 | 0.08 |
| 3 | 4.41 | 0.02 | 0.09 | 0.11 |
| 4 | 5.52 | 0.06 | 0.03 | 0.09 |
| 5 | 8.42 | 0.12 | 0.08 | 0.20 |

tion met with in the river. Such salts when acidified will give sulfur dioxide and, if appreciable amounts of the gas are carried away in preparing the blank, high results will be obtained. To settle this point, an experiment was made throughout a series of absorptions in which a guard tube containing hydrogen peroxide followed the cadmium acetate bottles. Further, the cadmium sulfide formed was filtered off and the iodine absorptions of the precipitate and of the filtrate were determined separately. In this way, any sulfur dioxide, as sulfite, would be shown either in the filtrate or, should it have passed on, would be trapped in the peroxide solution. The results are shown in Table II.

From these experiments it would appear that sulfur dioxide due to decomposition of thiosulfates (or sulfites) in acid solution accounts for 0.1 to 0.2 p.p.m. of sulfur as sulfide, which will be lost in the blank by the gassing process and which will thereby cause the final figure to be too high by that amount. This acts in the opposite direction from most other possible errors, which usually tend towards the loss of hydrogen sulfide.

## Conclusion

For the direct technique developed in the London County Council laboratory it can be claimed that it produces results which agree closely with those for sulfides measured by a standard reabsorption method, providing due precautions are taken in carrying out the latter. Also, that it is at least as accurate as any other method for technical purposes. The technique has advantages over the absorption method, for it is simple, there is less risk of loss of gaseous hydrogen sulfide, and, in particular, it can be combined and worked in conjunction with the Winkler method for dissolved oxygen, providing a two-way measure of pollution in terms of iodine either absorbed or liberated.

## Summary

The Winkler method of estimation of dissolved oxygen depends on the liberation of iodine equivalent to the amount of oxygen present. In polluted waters in which oxygen is absent, the Winkler method can be extended to measure oxygen deficiency in terms of iodine absorption. This deficiency is caused principally by sulfides and hydrogen sulfide. A technique has been developed to give a useful routine method for accurate determination of total sulfides. The method has the double advantage that either dissolved oxygen or total sulfides, whichever is present, can be estimated from the one sample.

## Acknowledgment

The authors wish to express thanks and acknowledgments to C. J. Regan, chemist-in-chief, London County Council, for his advice and encouragement.

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# Industrial Wastes

## TREATMENT OF AMMONIA STILL WASTES BY THE ACTIVATED SLUDGE PROCESS*

By W. W. Mathews

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On October 27, 1950, an experiment was started to determine to what extent ammonia wastes could be treated and phenol effectively destroyed by the activated sludge process. Ammonia liquor from the Gary, Ind., coke plant of the U. S. Steel Company was pumped to the main interceptor on this date and continued without interruption until April 30, 1951. The liquor was discharged at a uniform rate throughout 24 hr. The first loading was approximately 10 per cent of the total load expected. From time to time the load was increased as the experiment progressed.

### Local Conditions

The Gary treatment plant is connected to about 200 mi. of combined sewers. Some of the heaviest rain storms have occurred in January and February. Excessive runoff could have interfered materially with this experiment. At no time during the period were there any severe storms. Heavy runoffs occurred on a few days, but these were caused by melting snow. Generally speaking, ideal conditions prevailed for the entire period of the experiment.

### Biochemical Oxidation of Phenol

Using a biological process to destroy phenol is not a new development. Numerous references (1)(2)(5)(6)(7) are available on the use of sprinkling filters and activated sludge for this purpose. Some of the references report experimental work, whereas others record plant operation. The Dow Chemical Company, Midland, Mich., operates a plant including sprinkling filters and an activated sludge plant in series, where large quantities of phenol are destroyed each day. As far as the writer has been able to ascertain, this is the largest phenol destruction project in the world (6)(7). The Milwaukee, Wis., activated sludge plant treats phenolic waste with no difficulty. Probably many plants, either of sprinkling filter or activated sludge types, throughout the country treat this waste or gas plant wastes containing phenol; if it is in low concentrations and has caused no trouble, the operator may not be aware of its being present in the raw sewage.

### The Problem at Gary

With the reference given heretofore, the question may arise as to why the experiment at Gary was necessary. The south end of Lake Michigan which serves as a source of water supply for the four Calumet area cities (East Chicago, Gary, Hammond, and Whiting, Ind.) and the South Side filtration plant of Chicago, Ill., is a critical area as regards pollution. It is mandatory for all municipalities and industries in the area, as a result of a suit by the State of Illinois against the four cities, the State of Indiana, and the industries, to abate and keep all pollution out of the lake. This was

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agreed upon at hearings before a Master in Chancery, appointed by the U. S. Supreme Court. Certain stipulations were set up and agreed to by the industries.

Gary, having a treatment plant in operation at the time, was excused from the suit. East Chicago and Hammond also had plants in operation and were likewise excused. The city of Whiting agreed to take steps to stop its pollution of the lake. Whiting did not have a sewage treatment plant in operation then and has none in operation now. Arrangements were made by Whiting to have its sewage treated in the Hammond plant for the present. Since the suit, several millions of dollars have been expended by industry in constructing new sanitary sewer systems, connecting to municipal sewer systems, and making process changes (10).

The physiography of the Calumet area is such that effluents from all sewage treatment plants and industries which discharge into the Grand Calumet River flow in great part into the south end of Lake Michigan. Since phenol had never been a pollutant as far as Gary was concerned it was necessary to determine how efficiently it could be destroyed if the treatment of ammonia wastes was to be undertaken as an operational routine. The writer was not enthusiastic about starting the project. It was obvious that if appreciable amounts of phenol passed through the treatment plant and finally into Lake Michigan, the city of Gary would be responsible for this pollution.

Estimates based on past performance of the Gary plant, insofar as reduction of 5-day B.O.D. was concerned, indicated that 95 per cent destruction might be expected. If this estimate proved to be correct, from 75 to 100 lb. of phenol might be discharged into the Grand Calumet River daily. Some of this, in turn, would find its way into the water supplies of the various cities. If the experiment was to be successful from a treatment standpoint, it meant in this area practically 100 per cent destruction would be required.

Study of the problem indicated that certain basic data should be collected during the progress of the experiment and, as much as possible, established as positive facts. These were as follows:

1. Whether the ammonia wastes could be treated effectively, and the efficiency with which phenol could be destroyed.
2. The effect on the treatment process of the variable factors in the ammonia wastes.
3. The effect of the wastes on gas production.
4. Data which would serve as a base in computing fair costs of treating the wastes.

The list, of course, does not purport to cover all the research work possible on this problem. If obtained, however, the data would give a starting point for a more detailed examination of the problem.

The project was cleared as an experiment with the State of Illinois through C. W. Klassen, State Sanitary Engineer, by B. A. Poole, Director of Environmental Sanitation, State of Indiana.

### Stipulations Controlling the Experiment

Before proceeding with the project certain stipulations were set up by the Gary Sanitary District, as follows:

1. Ammonia wastes should be discharged at a uniform rate throughout 24 hr.
2. No change in load should be made except as specified by the District.
3. The waste would be shut off immediately if necessary.
4. The test continue for several months, including the month of lowest sewage temperature.

The maximum load expected was from 1,500 to 2,000 lb. of phenol per day in 500,000 gal. of ammonia still liquor. The liquid load was estimated on the basis of 25 gal. of water per ton of coal coked. Phenol content as shown by past analyses was quite low, amounting to less than 0.1 lb. of phenol per ton of coal coked, and this without dephenolizers, as there are none at the Gary plant. E. C. Kennedy, superintendent of the Gary coke plant, stated that the low phenol content results from the coal mix, which contains a higher percentage of low volatile coal than is ordinarily used at most coke plants.

### Preliminary Investigations

About four weeks before the experiment started, technicians from Mellon Institute brought in the necessary laboratory apparatus, including a Beckman B. spectrophotometer. Joseph H. Wells, then Senior Fellow at the Institute, made all arrangements for the laboratory setup. Preliminary determinations were run on river water samples, the raw and clarified sewages, and the final effluent. A few parts per billion were found, but the results were spotty. Checks were made with the local hospitals and a plastics industry to find if phenol was being used. No phenol was being discharged from any of these sources and the plastics industry had none in stock. It was concluded that these tests were not significant.

Treatment results at Dow Chemical Company (6) showed that with lower sewage temperatures in the winter months there was a decrease in the phenol removal, particularly in the sprinkling filter plant. Experimental work (3)(4) has shown that the rate of oxygen utilization by activated sludge and sludge-sewage mixtures decreases with lowering temperatures. With the experiment starting in October, facing decreasing temperatures and increased loadings, it was obvious that the critical point would be reached when the raw sewage was at the lowest annual temperature. From past records this should occur some time in February. On February 11, 12, and 13 raw sewage temperatures of 48°, 47°, and 49° F. were noted. Initially the sewage temperature was 65° F.; at the finish, 60° F. With the completion of this cycle the experiment ceased.

### Loads Expected from Waste

Preliminary studies indicated that the increased loading from phenol alone might total about 20 per cent of the normal secondary loading. The theoretical oxygen demand of phenol has been shown to be 2.38 lb. per pound of phenol (1). Laboratory tests showed that with synthetic phenol solution this was 1.9 + lb. and that the 5-day B.O.D. is quite close to the ultimate B.O.D. Nothing was known about the 5-day B.O.D. of the ammonia wastes, but later determinations showed this ranged from 1,200 to 1,900 p.p.m. as it left the stills. At no time was it

**TABLE I.—Analysis of Ammonia Still Wastes[1]**

| Constituent | P.P.M. |
|---|---|
| Free lime, CaO | 0 to 6,940 |
| Calcium, Ca | 1,900 to 3,000 |
| Magnesium, Mg | 50 to 750 |
| Sodium, Na | 50 to 60 |
| Free ammonia, $NH_3$ | 60 to 1,820 |
| Carbonates, $CO_3$ | 1,700 to 3,600 |
| Carbon dioxide, $CO_2$ | 90 to 595 |
| Sufate, $SO_4$ | 110 to 375 |
| Chloride, Cl | 2,300 to 2,800 |
| Thiosulfate, $S_2O_3$ | 160 to 245 |
| Thiocyanate, CNS | 115 to 325 |
| Cyanide, CN | 52 |
| Iron oxide and alumina, $R_2O_3$ | 40 to 660 |
| Silica, $SiO_2$ | 100 to 170 |
| Phenol | 400 to 550 |
| Total solids | 7,700 to 20,000 |
| Volatile | 7 to 46[2] |
| Suspended solids | 1,000 to 2,000 |

[1] A combination of two complete analyses plus data noted during experiment. Dilution factor of sewage to ammonia wastes varied from 40:1 to 50:1.

[2] Per cent.

**TABLE II.—Monthly Average Phenol Loadings and Miscellaneous Data; October, 1950, through April, 1951**

| Month (1950–51) | Flow (m.g.d.) | Phenol (p.p.b.) | | Phenol (lb.) | | pH | | | | Alkalinity (p.p.m.) | | | Temp. Raw Sew. (° F.) | Ammonia Still Liquor | | | Total Phenol (lb.) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw Sew. | Final Effl. | Raw Sew. | Final Effl. | Amm. Still Liq. | Raw Sew. | Mix. Liq. | Final Effl. | Amm. Still Liq. | Raw Sew. | Final Effl. | | (g.p.d.) | Total $NH_3$ (p.p.m.) | CaO (p.p.m.) | Raw Sew. | Final Effl. |
| Oct.[1] | | | | | | | | | | | | | | | | | 918[2] | 1[2] |
| Av. | 21.30 | — | — | — | — | — | 7.0 | 7.3 | 7.3 | — | 236[2] | 238[2] | 66 | 43,000[3] | 308[3] | 504[3] | | |
| Max. | 23.73 | — | — | — | — | — | 7.3 | 7.5 | 7.4 | — | 272[2] | 260[2] | 68 | 43,000[3] | 770[3] | 700[3] | | |
| Min. | 16.51 | — | — | — | — | — | 6.1 | 6.8 | 6.8 | — | 204[2] | 220[2] | 64 | 43,000[3] | 130[3] | 380[3] | | |
| Nov. | | | | | | | | | | | | | | | | | 10,127 | 9 |
| Av. | 21.81 | 1,881 | 2 | 341 | 0.31 | 11.6 | 7.2 | 7.3 | 7.5 | 1,887 | 221 | 213 | 60 | 81,307 | 266 | 429 | | |
| Max. | 26.54 | 3,435 | 5 | 657 | 0.80 | 12.7 | 7.7 | 7.5 | 7.7 | 3,250 | 268 | 252 | 66 | 90,000 | 500 | 750 | | |
| Min. | 19.99 | 848 | 0 | 136 | 0 | 9.9 | 6.5 | 7.0 | 7.3 | 1,150 | 152 | 168 | 56 | 36,700 | 130 | 80 | | |
| Dec. | | | | | | | | | | | | | | | | | 13,401 | 18 |
| Av. | 20.63 | 2,535 | 4 | 432 | 0.59 | 11.5 | 7.3 | 7.3 | 7.4 | 2,306 | 228 | 222 | 55 | 151,770 | 400 | 568 | | |
| Max. | 28.12 | 4,194 | 11 | 725 | 1.76 | 12.5 | 7.7 | 7.6 | 7.7 | 5,300 | 300 | 256 | 57 | 194,400 | 670 | 1,800 | | |
| Min. | 17.37 | 1,213 | 0 | 210 | 0 | 9.5 | 6.5 | 6.9 | 7.1 | 1,200 | 108 | 148 | 53 | 86,000 | 210 | 0 | | |
| Jan. | | | | | | | | | | | | | | | | | 21,514 | 23 |
| Av. | 23.05 | 3,617 | 4 | 694 | 0.75 | 10.9 | 7.7 | 7.3 | 7.5 | 3,735 | 224 | 232 | 53 | 225,948 | 775 | 530 | | |
| Max. | 27.00 | 7,270 | 20 | 1,530 | 3.77 | 12.7 | 8.3 | 7.5 | 8.3 | 6,100 | 336 | 272 | 56 | 280,800 | 1,820[4] | 1,290 | | |
| Min. | 18.21 | 97 | 0 | 20 | 0 | 9.7 | 6.6 | 7.0 | 6.9 | 2,200 | 108 | 144 | 51 | 47,700 | 350 | 0 | | |
| Feb. | | | | | | | | | | | | | | | | | 23,402 | 15 |
| Av. | 20.70 | 4,870 | 3 | 836 | 0.52 | 11.4 | 7.8 | 7.3 | 7.3 | 4,322 | 233 | 234 | 52 | 281,680 | 884 | 770 | | |
| Max. | 26.10 | 10,046 | 6 | 2,090 | 1.17 | 12.2 | 8.7 | 7.7 | 7.5 | 6,950 | 320 | 284 | 54 | 331,000 | 1,250 | 3,230 | | |
| Min. | 15.79 | 3,370 | 0 | 334 | 0 | 10.3 | 7.0 | 6.9 | 7.0 | 2,500 | 164 | 180 | 47 | 197,000 | 420 | 0 | | |
| Mar. | | | | | | | | | | | | | | | | | 28,333 | 8 |
| Av. | 21.76 | 4,931 | 2 | 914 | 0.26 | 12.2 | 7.3 | 7.2 | 7.3 | 8,328 | 211 | 214 | 52 | 257,900 | 277 | 1,125 | | |
| Max. | 26.15 | 8,547 | 5 | 1,821 | 0.92 | 12.5 | 8.6 | 7.6 | 7.6 | 6,750 | 292 | 256 | 55 | 436,000 | 1,080 | 6,940 | | |
| Min. | 16.67 | 2,605 | 0 | 329 | 0 | 9.6 | 6.5 | 7.0 | 7.0 | 1,500 | 172 | 188 | 50 | 174,000 | 70 | 0 | | |
| Apr. | | | | | | | | | | | | | | | | | 47,339 | 9 |
| Av. | 22.89 | 8,242 | 2 | 1,578 | 0.31 | 11.9 | 7.3 | 7.2 | 7.3 | 2,905 | 216 | 224 | 55 | 429,667 | 159 | 1,084 | | |
| Max. | 27.80 | 12,390 | 7 | 2,280 | 1.40 | 12.6 | 7.7 | 7.5 | 7.6 | 7,500 | 272 | 252 | 62 | 518,000 | 410 | 3,060 | | |
| Min. | 19.44 | 2,650 | 0 | 474 | 0 | 9.6 | 6.6 | 7.0 | 7.0 | 1,350 | 120 | 168 | 52 | 320,000 | 70 | 400 | | |

[1] Experiment started in October. [2] For 8 days preceding experiment. [3] Five days only (27th to 31st). [4] Lime slaker out of service.

**TABLE III.—Monthly Average and Maximum Phenol Content of Ammonia Still Wastes November, 1950, through April, 1951**

| Month (1950-51) | Phenol Load[1] (lb./day) | Ammonia Still Liquor[1] (g.p.d.) | Phenol in Still Liquor[1] (lb./1,000 gal.) | Max. Phenol in Still Liquor (lb./1,000 gal.) |
|---|---|---|---|---|
| November | 341 | 81,307 | 4.2 | 7.6 |
| December | 432 | 151,770 | 2.9 | 3.8 |
| January | 694 | 225,948 | 3.1 | 5.9 |
| February | 836 | 281,680 | 2.7 | 7.0 |
| March | 914 | 275,900 | 3.3 | 4.5 |
| April | 1,578 | 429,667 | 3.7 | 5.4 |

[1] Average values.

possible to establish a direct relation between the pounds of phenol received on any one day and the 5-day B.O.D. of the ammonia wastes.

Table I shows results of analyses of the ammonia wastes. This table is a combination of complete analysis of two samples, plus a few additions on some of the items made during the test. This does not cover the field of ammonia wastes, but rather local conditions. As a result, a wide variation from the values given will be found in numerous articles in technical journals on this waste.

It will be noted from Table I that this is a complex waste. It may well be designated a "rough" waste to treat. Total solids may show variations from approximately 7,700 to 20,000 p.p.m., with volatile solids ranging from 7 to 46 per cent. Suspended solids range from approximately 1,000 to 2,000 p.p.m.

## Description of Experiment

The initial loading was just under 200 lb. of phenol per day in 43,000 gal. of ammonia waste (Table II). This was held constant until November 3, when the phenolic load was increased, presumably, to 400 lb. per day with a flow of 86,400 gal. of waste. It was found that although it was a simple matter to control the rate of flow, phenol load varied considerably with uniform flow. Loading in the secondary bracket—that is, during November—averaged only 341 lb. per day (Table III). Daily loading of phenol in this second bracket ranged from a low of 136 lb. to a maximum of 657 lb. Mixed liquor solids had been increased from 1,100 to 1,354 p.p.m. (Table IV). On November 2, and each day following when backpressure on the blower system permitted, a second blower was operated, usually from 4 to 8 hr. per day and sometimes longer.

The phenolic load was increased by increments up to March 21, 1951, when the total waste was discharged to the interceptor. This continued until the experiment was terminated. A railroad strike during the winter interfered with coal mixes at the coke plant and necessitated changes in coking time from 17 to 24 hr., along with temperature changes. In one month this caused the load to vary daily from a low of 20 lb. to a high of 1,530 lb. (Table II). These fluctuations did not affect the efficiency of the treatment process or the efficiency of the oxidation of phenol.

The highest concentration of phenol in the raw sewage was 12.3 p.p.m. This happened to come on the last day of the run. The final effluent that day showed no phenol. The fact that no phenol registered in the final effluent was not as important as the fact that the results all the way through were consistently low. A phenol content of 5 p.p.b. is equivalent to 1 lb. of phenol in the final effluent, with a flow of 24 m.g.d. On only 23 days of the experiment was a reading of 5 p.p.b. or more registered.

There were five days in which the final results were out of line with all others. The first was on December 2, 1950, when a heavy thaw and runoff increased the pumpage to 28.12 m.g. This required the operation of a second raw sewage pump for 12 hr., which reduced the detention period in the aerators to approximately 3.3 hr. dur-

TABLE IV.—Activated Sludge Plant Data,[1] October, 1950, through April, 1951

| Month (1950–51) | Flow (m.g.d.) | Susp. Solids (p.p.m.) | | | 5-Day B.O.D. (p.p.m.) | | | Susp. Sol. (p.p.m.) | | Sludge Return (%) | Air (cu. ft./gal.) | Total Air (1,000 cu. ft./day) | D.O. (p.p.m.) | | Aeration Period (hr.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw Sew. | Clar. Sew. | Final Effl. | Raw Sew. | Clar. Sew. | Final Effl. | Mix. Liq. | Return Sludge | | | | Mixed Liq. | Final Effl. | |
| Oct. | | | | | | | | | | | | | | | |
| Av. | 21.30 | 264 | 101 | 5 | 140 | 77 | 4 | 1,354 | 4,333 | 40 | 0.47 | 9,723 | 1.8 | 8 | 5.09 |
| Max. | 23.73 | 522 | 135 | 11 | 212 | 115 | 10 | 1,772 | 7,060 | 53 | 0.64 | 9,984 | 5 | 9 | |
| Min. | 16.51 | 104 | 68 | 2 | 62 | 28 | 1 | 972 | 2,500 | 34 | 0.38 | 9,065 | 1 | 6 | |
| Nov. | | | | | | | | | | | | | | | |
| Av. | 21.81 | 319 | 114 | 7 | 154 | 87 | 6 | 1,581 | 6,218 | 36 | 0.53 | 11,277 | 2.7 | 8 | 5.03 |
| Max. | 26.54 | 466 | 188 | 20 | 240 | 134 | 11 | 2,288 | 8,866 | 52 | 0.76 | 13,581 | 6 | 9 | |
| Min. | 19.99 | 157 | 65 | 2 | 97 | 46 | 4 | 1,044 | 3,684 | 29 | 0.41 | 9,174 | 1 | 7 | |
| Dec. | | | | | | | | | | | | | | | |
| Av. | 20.63 | 414 | 114 | 11 | 182 | 100 | 7 | 2,530 | 8,181 | 46 | 0.56 | 11,062 | 3.3 | 9 | 5.04 |
| Max. | 28.12 | 812 | 203 | 23 | 266 | 164 | 10 | 3,592 | 9,273 | 51 | 0.72 | 12,794 | 8 | 9 | |
| Min. | 17.37 | 190 | 49 | 3 | 111 | 66 | 3 | 461 | 7,823 | 32 | 0.33 | 9,308 | 1 | 7 | |
| Jan. | | | | | | | | | | | | | | | |
| Av. | 23.05 | 323 | 126 | 12 | 159 | 109 | 8 | 3,035 | 11,333 | 39 | 0.54 | 11,719 | 3.9 | 8 | 4.76 |
| Max. | 27.00 | 699 | 274 | 28 | 282 | 212 | 16 | 4,150 | 20,416 | 48 | 0.67 | 13,452 | 8 | 10 | |
| Min. | 18.21 | 133 | 80 | 4 | 104 | 67 | 4 | 1,886 | 7,508 | 30 | 0.41 | 9,829 | 0.6 | 5 | |
| Feb. | | | | | | | | | | | | | | | |
| Av. | 20.70 | 404 | 305 | 12 | 183 | 162 | 6 | 3,547 | 13,426 | 48 | 0.55 | 10,913 | 4.4 | 8 | 5.04 |
| Max. | 26.10 | 741 | 1,296 | 20 | 358 | 539 | 11 | 4,286 | 25,620 | 68 | 0.73 | 12,531 | 8 | 10 | |
| Min. | 15.79 | 212 | 85 | 7 | 83 | 54 | 3 | 2,500 | 8,358 | 39 | 0.44 | 9,555 | 2 | 6 | |
| Mar. | | | | | | | | | | | | | | | |
| Av. | 21.76 | 491 | 188 | 13 | 197 | 110 | 6 | 3,240 | 12,543 | 39 | 0.49 | 10,019 | 3.8 | 8 | 4.88 |
| Max. | 26.15 | 1,537 | 890 | 25 | 713 | 297 | 12.3 | 4,114 | 23,904 | 54 | 0.73 | 12,246 | 8 | 10 | |
| Min. | 16.67 | 222 | 78 | 6 | 103 | 50 | 3 | 2,328 | 7,460 | 24 | 0.38 | 8,121 | 0.6 | 5 | |
| Apr. | | | | | | | | | | | | | | | |
| Av. | 22.89 | 366 | 95 | 8 | 153 | 79 | 5 | 2,430 | 9,529 | 40 | 0.52 | 11,431 | 3.7 | 8 | 4.63 |
| Max. | 27.80 | 1,476 | 170 | 9 | 291 | 115 | 8 | 3,122 | 16,676 | 51 | 0.70 | 12,972 | 7 | 9 | |
| Min. | 19.44 | 169 | 71 | 7 | 93 | 37 | 2 | 1,778 | 7,530 | 30 | 0.35 | 8,842 | 0.8 | 7 | |

[1] Monthly averages.

ing that time. The final effluent carried a total of 1.8 lb. of phenol for this date, although loading at this time was only 414 lb. of phenol in the raw sewage. The short detention period in the aerators was responsible for this result. On December 4, the final effluent showed 1.7 lb. with a flow of only 19 m.g.d. The mixed liquor solids were out of balance on account of the high rate of pumpage on December 2; the total mixed liquor solids being only 473 p.p.m. explains the amount of phenol getting through the plant.

On January 3, 1951, the final effluent showed 17 p.p.b., with 2.6 lb. of phenol in the final effluent. The flow was low (19.23 m.g.) and all operating conditions were apparently normal. No reason was apparent for the high phenol result. Thawing on January 10, 1951, again required a second pump in service for 9.5 hr., with pumpage of 27.00 m.g. The short aeration period for this time again gave a high phenol content of 3.8 lb. in the final effluent, with a loading of 994 lb. of phenol. This demonstrated again the importance of an adequate detention period. On January 11, 1951, with less than 1 p.p.m. of D.O. at the end of aeration, the final effluent carried 1.60 lb. of phenol. Lack of D.O. was apparently all that was out of line on this date and indicated oxygen deficiency. Undertreatment probably gave the result shown.

The preceding data appear to be repetitive, but the information is given in detail because of its importance. With a combined sewer system, flows at any treatment plant will have a wide range from low to high, which interferes with the treatment process. This makes it impossible to produce at all times the high quality effluent desirable when treating an industrial waste that should be destroyed practically 100 per cent.

The total amount of phenol received at the plant during the period of test was 145,034 lb. Of this total, 83 lb. passed through the plant for an average of 0.44 lb. per day, or approximately 3 p.p.b. The reduction accomplished was 99.94 per cent.

Phenol determinations were made using the technique of the 4-aminoantipyrene test as described by Ettinger and Kroner (9).

### Nitrogen Determinations

Nitrogen determinations were run on raw and clarified sewages and the final effluent. Analyses were made for organic, ammonia, nitrite, and nitrate nitrogen. Ordinarily these are not run on raw and clarified sewages, except possibly in special cases where research work may be necessary. In order to have a complete picture of the process before and during the test, these were made daily for about two weeks before and until December 14. There was so little difference shown in the results that after this date they were run once a week, moving up one day each week.

At no time has there been overtreatment at Gary. Nitrates in the final effluent have always ranged from about 0.06 to 0.15 p.p.m. With exceptions of a few maximums up to 0.24 and 0.36 and one of 0.60 p.p.m., averages throughout the experiment stayed within previous limits (Table V). Final B.O.D. determinations have never been hampered by high nitrate content.

Organic and ammonia nitrogen showed very little variation from past records. Single maximums were somewhat higher, but averages for the entire period showed no marked change from previous data. Averages for organic nitrogen over the entire period were 14, 10, and 4 p.p.m. in the raw, clarified, and final effluent, respectively. Corresponding ammonia nitrogen averages were 14, 13, and 14 p.p.m. The changes were less than had been anticipated.

TABLE V.—Nitrogen Determinations[1], October, 1950, through April, 1951

| Month (1950–51) | Nitrogen (p.p.m.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw Sewage | | | | Clarified Sewage | | | | Final Effluent | | | |
| | Org. | $NH_3$ | $NO_2$ | $NO_3$ | Org. | $NH_3$ | $NO_2$ | $NO_3$ | Org. | $NH_3$ | $NO_2$ | $NO_3$ |
| Oct. | | | | | | | | | | | | |
| Av. | 15.0 | 10.9 | 0.03 | 0.10 | 11.2 | 12.0 | 0.03 | 0.11 | 5.9 | 12.0 | 0.16 | 0.11 |
| Max. | 21.3 | 16.0 | 0.10 | 0.60 | 16.2 | 16.0 | 0.10 | 0.60 | 9.0 | 16.0 | 0.50 | 0.60 |
| Min. | 10.6 | 4.0 | 0.01 | 0.06 | 8.7 | 6.0 | 0.01 | 0.06 | 4.2 | 4.0 | 0 | 0.06 |
| Nov. | | | | | | | | | | | | |
| Av. | 11.9 | 12.3 | 0.07 | 0.08 | 9.5 | 12.8 | 0.05 | 0.07 | 4.5 | 11.9 | 0.10 | 0.07 |
| Max. | 18.5 | 18.0 | 0.40 | 0.16 | 15.7 | 18.0 | 0.30 | 0.16 | 10.6 | 18.0 | 0.40 | 0.14 |
| Min. | 7.0 | 6.0 | 0.01 | 0.06 | 5.3 | 6.0 | 0.01 | 0.06 | 2.0 | 6.0 | 0.03 | 0.06 |
| Dec. | | | | | | | | | | | | |
| Av. | 14.8 | 16.8 | 0.18 | 0.12 | 8.7 | 16.1 | 0.17 | 0.09 | 3.2 | 15.7 | 0.16 | 0.08 |
| Max. | 20.7 | 28.0 | 0.30 | 0.26 | 10.6 | 24.0 | 0.28 | 0.16 | 3.6 | 22.0 | 0.40 | 0.18 |
| Min. | 7.0 | 8.0 | 0.10 | 0.08 | 5.3 | 10.0 | 0.01 | 0.06 | 2.5 | 8.0 | 0.05 | 0.04 |
| Jan. | | | | | | | | | | | | |
| Av. | 16.2 | 17.3 | 0.23 | 0.20 | 11.0 | 17.3 | 0.19 | 0.22 | 3.8 | 17.6 | 0.15 | 0.14 |
| Max. | 22.4 | 28.0 | 0.35 | 0.50 | 14.3 | 26.0 | 0.31 | 0.40 | 5.3 | 28.0 | 0.35 | 0.36 |
| Min. | 10.9 | 8.0 | 0.10 | 0.12 | 9.1 | 8.0 | 0.07 | 0.10 | 2.5 | 8.0 | 0.03 | 0.06 |
| Feb. | | | | | | | | | | | | |
| Av. | 17.4 | 19.3 | 0.56 | 0.15 | 26.4 | 22.0 | 0.60 | 0.13 | 4.1 | 21.3 | 0.53 | 0.09 |
| Max. | 19.6 | 24.0 | 0.70 | 0.24 | 37.2 | 30.0 | 0.85 | 0.20 | 5.0 | 30.0 | 0.75 | 0.12 |
| Min. | 16.0 | 10.0 | 0.48 | 0.10 | 11.8 | 12.0 | 0.40 | 0.10 | 3.1 | 10.1 | 0.15 | 0.06 |
| Mar. | | | | | | | | | | | | |
| Av. | 13.9 | 14.0 | 0.29 | 0.14 | 10.8 | 12.0 | 0.29 | 0.14 | 4.6 | 16.0 | 0.21 | 0.15 |
| Max. | 17.6 | 18.0 | 0.38 | 0.16 | 12.9 | 16.0 | 0.45 | 0.16 | 6.4 | 18.0 | 0.25 | 0.24 |
| Min. | 10.4 | 10.1 | 0.15 | 0.12 | 9.8 | 10.0 | 0.13 | 0.12 | 3.1 | 12.0 | 0.18 | 0.08 |
| Apr. | | | | | | | | | | | | |
| Av. | 11.9 | 10.0 | 0.06 | 0.10 | 8.75 | 10.0 | 0.06 | 0.10 | 4.12 | 14.0 | 0.06 | 0.09 |
| Max. | 14.6 | 16.0 | 0.18 | 0.16 | 10.6 | 12.0 | 0.15 | 0.12 | 4.5 | 16.0 | 0.13 | 0.12 |
| Min. | 8.7 | 6.0 | 0 | 0.06 | 7.6 | 6.0 | 0 | 0.06 | 3.6 | 12.0 | 0 | 0.08 |

[1] Monthly averages.

### Functioning of the Activated Sludge Process

During the progress of the experiment certain changes were made in the various parts of the activated sludge process (see Table IV). These included an increase in air blown, higher concentration of solids in the mixed liquor and return sludge, and an increased rate of return. None of these changes were made suddenly except that of return sludge, when, on February 1, 1951, a third pump was placed in operation, which was then operated continuously with the other two pumps until the end of the experiment.

### Air Requirements

Air, at the beginning of the test, was being supplied at between 9,000,000 and 10,000,000 cu. ft. per day. This was at an average rate of 0.47 cu. ft. of air per gallon of sewage. (Cubic feet of air per gallon of sewage is not a good unit to use in comparing the performances of activated sludge

plants, but it is a handy tool around a single plant. Cubic feet of air per pound of B.O.D. reduced is the unit ordinarily employed in making comparisons.)

On and after November 2, 1950, a second blower was operated for several hours per day whenever possible, the length of time being governed by the D.O. at the end of aeration. It was not always possible to operate this blower every day because of high backpressure on the blower system. Periods of high relative humidity always cause a rapid rise in pressure when diffuser tubes are partially clogged. With pressure above normal with one blower in operation, it is impossible to place a second blower on the line.

A D.O. of 3 p.p.m. at the end of aeration was desired. Although this was maintained throughout the test, as shown in Table IV, except for October and November, there were short periods when the D.O. was below 2 p.p.m. and one period of below 1 p.p.m. The amount of air supplied, as shown in Table IV, indicates a minimum use. Slightly more air would have been used if atmospheric conditions had permitted. In January, aerators 1 to 4 had clean tubes installed to ensure an adequate air supply until the experiment was completed. Ordinarily tubes are not changed at this time of the year because of the hazardous working conditions from ice forming on the floor of the aerators when drained.

It will be noted from Table IV that in February, the month of highest B.O.D. in the clarified sewage, the D.O. at the end of aeration was the highest for any month. There was only a slight increase in air over the previous month. The reason for this higher D.O. (also in January) was better distribution of air throughout the length of the four aerators where clean tubes had been installed. Clogging occurs in great part at the head end of the aerators, where return sludge mixes with the clarified sewage and mixed liquor. From one-fourth to one-third the length of the aerators may have a sluggish roll, where tubes are partially clogged, so that the computed aeration detention period does not give a true picture of actual conditions. Only with all tubes clean does the theoretical detention period agree with the actual period.

### Solids Concentrations

At the start of the test the mixed liquor solids content was about 1,100 p.p.m. By January, this concentration had been raised so that the average for that month was 3,035 p.p.m. As the ammonia waste load increased (Tables II and III), higher mixed liquor concentration followed (Table IV). Return sludge solids naturally increased with higher mixed liquor concentration. Initially, return sludge averaged about 4,300 p.p.m. and reached a high level in February, with 13,426 p.p.m. when mixed liquor solids was 3,547 p.p.m. Following February, which was the month of highest loading, solids were decreased so that in April they averaged 2,430 and 9,529 p.p.m., respectively. The last five days of April showed ranges in mixed liquor solids of from 1,778 to 2,010 p.p.m., with return sludge solids of 7,520 to 8,812 p.p.m.

It was intended originally to hold solids at 3,000 p.p.m. With the high organic loading in February, and with the higher concentration producing a very satisfactory 5-day B.O.D. in the final effluent, 3,547 p.p.m. was maintained with an average of 6 p.p.m. 5-day B.O.D. in the final effluent, and with a range of 3 to 11 p.p.m. for the month. Working with high concentrations of solids, wasting had to be scheduled carefully to prevent solids building up to excessive levels. It was noticed that at these levels, solids beget solids, and quite rapidly.

### Return Sludge Rate Changes

Rate of return sludge has always been maintained at a high level at Gary. When the plant was placed in operation in August, 1940, sludge return at 25 per cent was tried. In a short time septic conditions developed in the return sludge and the rate was increased. For the first 10 months of 1950, the average rate of return was 35.9 per cent. This rate was maintained by operating two out of three return sludge pumps available. These pumps were operated continuously and any changes in the percentage rate were caused by variations in the sewage flow.

To produce a good final effluent with the activated sludge process, aerobic conditions must be maintained throughout the secondary process. This is accomplished by supplying air in such quantities that a satisfactory D.O. is maintained at the end of aeration, plus a rate of return that will permit the return sludge to enter the aerators before septic conditions have had time to develop. The sludge mixture has an extremely high oxygen demand and the supply ceases as soon as the mixed liquor flows over the weirs of the aeration basins. It is obvious that the quicker the sludge can be returned to the aerators, the less chance there is of deterioration due to lack of oxygen. The D.O. of return sludge in overflow manholes at the secondary clarifiers ranges from 1.2 to 3.6 p.p.m. Time of flow from manholes to aerators is from 2 to 2.5 min.

Sludge return uses relatively little power, as it is a low-head pumping operation. The power requirement (minimum) for Gary air supply is one 300-hp. gas engine driving a 7,000-cu. ft. blower; just above minimum requirements may necessitate an additional unit for 2 hr. per day. Motors for the three return sludge pumps total 60 hp., divided into 15-, 20-, and 25-hp. units. Only two of these are operated under average sewage load conditions. If either additional air or return sludge capacity is needed, it has been found at times that it is more economical to run a 15- or 20-hp. motor for 24 hr. than to run a second blower unit for 2 hr. It has been demonstrated that with three return sludge pumps in operation (third unit placed in service), a better final effluent can be produced than by operating a second blower part time.

About February 1, 1951, sludge began to build up on the floor of the secondary clarifiers. (Table IV indicates mixed liquor and return sludge solids at the highest level in February.) Soundings taken three times daily normally show 6 in. of sludge at the center baffles of the 75-ft. square final clarifiers, less than 6 in. at the quarter point, and the same at the outer walls. Soundings are taken by conventional sounding rods with 6-oz. bottles mounted front and back at 6-in. intervals. About this date soundings showed a build-up to 12 in., and in one case to 18 in., at the center. This showed that the rate of return was too low and a third unit was placed in operation on February 1 to bring the sludge blanket down to normal level. All three return sludge pumps were then operated continuously until the end of the experiment, when one unit was shut down. During the summer months (1951) clogged tubes again interfered with aeration and the third pump was again placed in operation. This cleared up a cloudy final effluent. At this time it was impossible to operate a second blower because of high backpressure. When cleaned tubes had been installed in six aerators, the extra unit was again shut down.

### Load Changes on Treatment Process During Experiment

Table VI shows the average daily 5-day B.O.D. loading in the clarified sew-

**TABLE VI.—5-Day B.O.D. in Clarified Sewage, Average Daily Loading October, 1950, through April, 1951**

| Month (1950–51) | B.O.D. Loading | | Air per lb. B.O.D. Removed (cu. ft.) | Aer. Eff., Lb. B.O.D. Dig. per Lb. $O_2$ Blown (%) |
|---|---|---|---|---|
| | (lb./day) | (lb./day/cu. ft. aer. cap.) | | |
| October | 13,676 | 17.1 | 755 | 7.82 |
| November | 15,839 | 19.7 | 758 | 7.79 |
| December | 17,282 | 21.5 | 686 | 8.61 |
| January | 20,944 | 26.1 | 601 | 9.83 |
| February | 27,916 | 34.8 | 406 | 14.55 |
| March | 19,945 | 26.0 | 533 | 11.08 |
| April | 15,125 | 18.9 | 801 | 7.39 |

age. The total for October can be taken as a base, because this checks quite closely with the load of the previous October and succeeding months showed only normal variation.

The heaviest organic loading in the clarified sewage occurred during the month of February. This resulted from a combination of two factors—stoppages in the sludge hoppers and raw sludge suction lines caused a greater depth of raw sludge than usual to be held in storage in the primary clarifiers, plus the increased load of the ammonia wastes. The high level of sludge in the primary clarifiers caused the clarified sewage to carry more suspended solids than usual, almost three times the normal amount. Clearing up stoppages covered the period from February 23 to March 11, after which no difficulty was experienced in pumping raw sludge. It will be noted (Table IV) that there was a drop in clarified suspended solids and 5-day B.O.D. in March and also in April.

The Gary plant was designed for 170,000 population loading with 10 aerators in service. Assuming a 35 per cent reduction of 5-day B.O.D. in the primary clarifiers, this would give approximately 110,000 equivalent population loading for the secondary process. Equivalent population loading from February clarified sewage was 164,000, with only six aerators in service. This gave a loading in terms of pounds of 5-day B.O.D. per 1,000 cu. ft. of aerator capacity much higher than usual, amounting to 34.8 lb. This previously had reached 22 lb. only, and the average for the year 1950 was 17.5 lb. Increased loadings may be obtained through cutting down on aeration capacity by reducing the number of aerators in service. If this is done, however, the aeration period may be decreased to where the quality of the final effluent is degraded and the operator will find that a better effluent can be produced with a lighter loading and lower aeration efficiency.

There is no reason why loads of 35 lb. or more of 5-day B.O.D. per 1,000 cu. ft. of aeration capacity cannot be used, provided adequate air supply is available and a high rate of sludge return is included in the plant design. It is interesting to note that the "Tentative Standards for Sewage Works," compiled by the Upper Mississippi River Board of Public Health Engineers and the Great Lakes Board of Public Health Engineers (Jan., 1951) specify that "tank volume shall have 30 cu. ft. per lb. of 5-day B.O.D. in the aerator inlet." This is equivalent to 33 lb. per 1,000 cu. ft. of aerator capacity.

During February, daily loadings in the clarified sewage ranged from a low of 9,000 lb. to a high of 99,600 lb. At no time during the experiment were shock loadings experienced with either high alkalinity or acidity. Once the flow of the waste (pH 9.6 to 12.7, with average of 11.5) was started, an alkaline stability was established in the raw and clarified sewages.

The maximum load of 99,600 lb. occurred on February 3, 1951. This was caused by a heavy carryover of a mixture of primary and secondary solids from the primary clarifiers during a wasting period of 5 hr. Ordinarily, wasting was for 2 or 3 hr. with one of the return sludge pumps shut down. This was to decrease the rate of waste sludge into the primary clarifiers and to prevent an excessive carryover. On this date wasting for 5 hr. was sched-

uled and the outside operator failed to shut down one of the pumps. This gave a carryover which showed 1,296 p.p.m. in the composite clarified sample, so during the wasting period it must have been much higher. The B.O.D. composite showed 539 p.p.m. Expressed in pounds of 5-day B.O.D. loading this was 99,667 lb., with an equivalent population load of 585,000. The loading on the aerators was 124 lb. B.O.D. per 1,000 cu. ft. of aerator capacity and the air per pound of B.O.D. reduced amounted to 124 cu. ft. These two figures happen to be in empirical agreement, which is of no significance.

The total of this load was not known for five days, but on the following day the clarified cone had about 8 in. of solids after settling, whereas ordinarily this is only about 1 in. Wasting was started at once and maintained on a correct routine so that the solids in the aerators were brought down to a normal content. This heavy load was not reflected by a poor final effluent. Suspended solids in the final effluent were 11 p.p.m. on the preceding day, rose to 20 p.p.m. on the day of heavy loading, and on the succeeding day were down to 10 p.p.m. The final effluent 5-day B.O.D. was 7, 6, and 5 p.p.m. for the three days. The sludge index showed the greatest variation, being 119, 252, and 121 for the corresponding days.

This loading may be called a false loading, in that it originated in the process itself and is one that would not ordinarily occur. It may also be stated that the carryover was primed or seeded for the biological process, as it carried large quantities of secondary sludge, which had the same pH as the secondary process. Granting all this, the analyses showed that there was a heavy loading of organic material which required treatment. It is further agreed that if the attempt was made to operate on this level for any length of time, with the small amount of air supplied, the previous normal operation of the process would be upset.

The results of this day's operation indicated, however, that in buffering the plant for the loading from the ammonia wastes, the solids concentration in the mixed liquor was higher than required. Also, that there was considerable reserve capacity at 3,500 p.p.m. in the mixed liquor present that day. It was concluded that if at some future time the treatment of ammonia wastes was undertaken as a regular treatment routine, the concentration of solids in the mixed liquor would be built up at a slightly lower rate than was employed in the experiment.

### Aeration Efficiencies

Also shown in Table VI is the amount of air supplied per pound of 5-day B.O.D. reduced and the aeration efficiency, which is pounds of 5-day B.O.D. reduced per pound of oxygen blown (not corrected to standard conditions). It will be noted that with the exception of November, heavier aerator loadings required less air per pound of 5-day B.O.D. reduced. Table VI shows that with increased aerator loadings higher aeration efficiency may be obtained.

Since daily organic loadings on the secondary process are beyond the control of the operator, oxygen utilization efficiency is likewise beyond his control. He may have worked out an efficient operating routine as regards concentration of mixed liquor solids, amount of air blown, and rate of sludge return, and produce a highly polished effluent. The efficiency, however, is going to vary from day to day: with an increased load and with the same amount of air, it will rise; with a decrease in load, it will decline.

### Effect of Wastes on Treatment Process

No one could predict how the process would react to the treatment of am-

monia wastes. Changes were expected and the aerators, final clarifiers, and final effluent were closely watched. Analytical results were checked by visual inspection of the aerators and final clarifiers, and although at times results would indicate a satisfactory effluent, the appearance of the effluent would indicate some changes were needed. Most frequently noticed was a cloudy effluent which tested low in suspended solids. However, this cloudiness usually indicated undertreatment from an air supply viewpoint. A slight amount of air added at various times proved this was what was needed in a majority of cases.

### Mixed Liquor and Sludge Index

The mixed liquor gradually lost its brown color as the load increased and assumed a grayish cast. At no time did the mixed liquor have as bright a color, if that word can be used, while treating the ammonia wastes, as when treating a typical domestic sewage. Yet, despite this drab appearance, the B.O.D. in the final effluent was consistently good. Sludge index records indicate that for about two months adjustments were being made in the treatment process to find a good operational routine. Monthly averages of sludge indices for the 6-month period, November to April, were as follows:

| Month | Sludge Index Av. | Max. | Min. |
|---|---|---|---|
| November | 224 | 398 | 105 |
| December | 180 | 312 | 87 |
| January | 100 | 282 | 41 |
| February | 83 | 252 | 37 |
| March | 84 | 249 | 65 |
| April | 140 | 369 | 81 |

During the first two months the solids concentration was being built up, so that by December 20, 3,000 p.p.m. had been reached. This level was maintained or slightly exceeded until about the middle of April, when the solids were gradually reduced until the waste was shut off. Air supply was from one and two blowers each day when possible. After February 1, when a third return sludge pump was placed in operation, the index more or less stabilized, with fewer peaks than in the previous months. From March 1 to 17, inclusive, the sludge index varied only between 64 and 80, with ranges in loading from 9,000 to 48,000 lb. of 5-day B.O.D. in the clarified sewage and with mixed liquor concentrations of from 2,456 to 4,114 p.p.m. It will be noted that the greatest variable during this period was in the loading, which had a range from low to high of approximately 500 per cent.

The treatment process was quite sensitive as regards daily sludge index variations. High loads cannot be determined until five days after they have occurred. Therefore, daily changes in air supply cannot be made to follow changes of load. At times of high loading, with one blower in service, or if a second blower happened to be in operation, the sludge index might vary overnight from around 100 to 300. When this occurred and the index of the previous day was computed, the sludge index could be brought back to normal if extra air could be supplied. High sludge index did not always mean high suspended solids in the final effluent, as shown by the following results at various times:

| Sludge Index | Susp. Sol. in Fin. Effl. (p.p.m.) |
|---|---|
| 181 | 3 |
| 199 | 6 |
| 392 | 7 |
| 312 | 6 |
| 382 | 21 |
| 342 | 20 |
| 123 | 23 |

Pumpage rate probably had more effect on the suspended solids content of the final effluent than any other factor. On one day of high pumpage the sludge index was 41 and the suspended solids concentration in final effluent was 28 p.p.m.

### Secondary Clarifiers

Most of the time when treating domestic sewage only, the secondary clari-

fiers are clear and the raking mechanisms can be seen. About two weeks after the experiment started, a light solids blanket had risen to about 4 in. below the water surface. This left a clear zone over the top of each secondary clarifier and final effluent was skimmed out of this zone over the saw toothed weirs. This blanket held stationary throughout the experiment and never lifted so that a high solids content appeared in the final effluent. Two weeks after the waste was shut off the rakes were again visible. This was on May 13, and they had not been seen since the previous November.

## Gas Production

Although treatment of waste did not inhibit the aerobic process, it did cause a drop in gas production. In November, a month of light loading of ammonia wastes, the gas production increased about 20,000 cu. ft. per day over October. This was quite encouraging and it was thought that possibly the alkaline waste would tend to raise gas production. Through December, and up to and including March, each succeeding month showed a decrease. April showed some recovery, but not back to normal. With the waste cut off at the end of April and the contents of the digesters being gradually displaced with raw sludge containing no waste, gas production started to increase. May and June both showed increases and apparently conditions were back to normal in the multi-digestion system. Total gas production for the 6-month period from November to April, over the past seven years showed the 1950–51 period ranked sixth.

Digestion was irregular with the waste present. There were periods when gas production decreased for a week or two, followed by a recovery period. This was repeated several times from January to April, inclusive, during the period of heavier loadings of waste. Recirculation and agitation were tried to overcome this handicap, but apparently had no effect. This adds to the cost of treatment. There is the loss of gas, plus the increased amount of gas required to furnish additional air needed for the increase in loading from the waste.

## Summary

It has been demonstrated that ammonia wastes containing up to 12.3 p.p.m. of phenol, in terms of sewage flow, can be treated successfully by the activated sludge process at Gary, with the waste having a composition as noted in Table I. It has also been demonstrated that the anaerobic process is inhibited by the waste that is pumped to the digesters with the raw sludge, resulting in a decrease in gas production.

## Conclusions

Conclusions drawn from the experiments described herein are as follows:

1. Phenol in the ammonia still waste, in terms of sewage flow, could be treated in concentrations up to 25 p.p.m. and with approximately 100 per cent effectiveness, providing there was no excessive build-up in concentration of some other toxic substance that might inhibit the aerobic process.
2. Solids concentration in the mixed liquor must be increased to take care of the increased load.
3. Extra air must be supplied because of the additional organic load imposed on the treatment process.
4. A higher rate of sludge return is required if air requirements are to be kept to a minimum.
5. Complete destruction of phenol cannot be effected with the aeration period greatly reduced.

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## DISCUSSION


By S. Mogelnicki

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Mr. Mathews has presented a very comprehensive and significant paper. To some of us in industry, however, its greatest significance is not in the technical data revealed, but in the fact of cooperative endeavor on the part of a city and one of its industries toward the solution of a local, but also widespread, problem.

He has shown that the Gary municipal sewage plant can treat ammonia still wastes very successfully. The questions remaining are: "Will such a project be undertaken?"; "If so, when?"; "If not, why not?"; and "What action is to be taken?"

Successful pollution control nationally is going to call for a great deal more of this type of cooperation between municipalities and their industries.

To those engaged in large-scale destruction of phenol, there seems to have been a considerable lack of interest in, or perhaps understanding of, the biological oxidation of phenol. This large-scale experiment is, therefore, an encouraging sign, as is also the interesting laboratory work of A. Henderson, of the Hydrotechnic Corporation. Such work will no doubt give welcome assistance to those who may be confronted with similar waste treatment problems.

It should be emphasized that biological oxidation of phenol is accomplished quite easily with ordinary soil bacteria and does not require a specially devel-

oped culture as some people have been led to believe. It has been found that phenol is one of the most readily oxidized organic compounds. With well-seeded dilution water, the 5-day B.O.D. of phenol will be very close to the theoretical 2.38 p.p.m. per part of phenol. This can be confirmed by an oxygen consumed test, although any test which does not completely destroy phenol is of limited value. For treatment of phenolic wastes, it is believed advisable to design a plant on the basis of complete oxidation.

Mr. Mathews' paper does not discuss the preservation of samples for analysis, and it can only be presumed that the determinations made were accurate. It should be pointed out that, in working with wastes of this type, special precautions must be taken to inhibit bacterial oxidation in stored samples in order to prevent erroneous results. Spot samples taken through the treatment plant, incidentally, are an excellent check on results of composite samples.

With two or three exceptions, the writer is in general agreement with Mr. Mathews' conclusions. Specifically, exception would be taken with regard to his conclusions on solids build-up, effects on gas production, and air requirements.

Considering the Gary experiment as a whole, it is believed that a misjudgment was made in apparently pre-supposing that certain modifications in process would be necessary in handling the ammonia still wastes. Because certain modifications were made before any phenolic wastes were received and continued throughout the experiment, it has still not been proven whether or not the plant could handle these wastes in normal operation. Nor has the experiment shown the degree to which modifications, if any, are needed.

Specifically, it might be noted that the plant was evidently prepared for the still wastes by increasing the concentration of solids in the aeration tanks substantially above normal. Had the plant been left in normal operation instead, then the quality of the effluent in terms of phenol would have indicated if and when more solids were needed and a determination of the amount needed could then have been made. Samples taken through the aeration tanks would have demonstrated how and where the phenol disappeared in the process. Also, it is quite probable that 90 per cent of the phenol was oxidized in less than 30 min.

As a matter of fact, the writer believes that no build-up of solids was necessary; that the normal concentration was ample to handle the additional wastes satisfactorily. This view would seem to be supported by the fact that, although the daily loadings of phenol varied widely, the phenolic content of the effluent was consistently low. It seems to be supported, also, by the experience reported on December 4, when the solids concentration was out of balance. Solids were only 473 p.p.m., whereas they were apparently being carried at an average of about 2,500 p.p.m.

On that day, it was noted that 1.7 lb. of phenol, or about triple the usual amount, was discharged in the effluent. On the face of it, this might appear to be a tremendous drop in efficiency. However, if looked at from the viewpoint of phenol destroyed, it becomes quite another matter. The average daily phenol input for December was 432 lb. If December 4 can be assumed to have been "average," then the plant on that day removed 430.3 lb. of phenol, even though the mixed liquor solids were less than one-fifth of their average concentration for the month. In other words, the drop in efficiency was actually very slight.

The results of the Gary experiment showed a decrease in gas production during treatment of the still wastes. However, this might have been due to garbage or other factors, such as sul-

fates or detergents. Since it is known that phenol undergoes complete destruction under anaerobic conditions, there is no justification for such a conclusion in view of the lack of conclusive supporting data.

Mr. Mathews made an interesting statement when he said that loadings of 35 lb. of B.O.D. per 1,000 cu. ft. of aeration capacity could be used. The writer is of the same opinion, but the loading depends on the rate at which the waste can be oxidized. In the experiment at Gary, the period of highest loading in terms of pounds of B.O.D. per 1,000 cu. ft. of aerator capacity was also the period of highest suspended solids in the clarified sewage. This is very significant and should not be falsely interpreted to mean that an equivalent loading in true solution could be oxidized, unless the rate of oxidation was the same as the previous rate of removal. If the loading were expressed as pounds of B.O.D. oxidized per 1,000 cu. ft. of aerator capacity per hour of aeration, it would take into account the rate of oxidation. The day of so-called false loading mentioned by Mr. Mathews was indeed a false loading, which was subsequently removed to the digesters.

Mr. Mathews was very observing of his activated sludge process but experience has shown that a "poor-looking" activated sludge is not necessarily an indication of something wrong in the process. On the contrary, some of the best results have been obtained with gray, drab sludges. Also, cloudiness of the effluent could be the result of over-aeration, as well as under-aeration.

The air requirements of a sewage activated sludge plant and an industrial wastes activated sludge plant can vary considerably. This is evidenced by the necessity of maintaining 3 p.p.m. of dissolved oxygen at the end of aeration in the former, whereas in the latter, excellent operation and results can be obtained with less than 0.5 p.p.m. of dissolved oxygen. As a further comparison of activated sludge plant information, the following data are presented from operating experiences at Midland. The activated sludge plant for treatment of phenolic wastes uses 4,000,000 cu. ft. of air per day in the treatment of 15 to 20 m.g.d. of waste. This is equivalent to 0.20 to 0.25 cu. ft. of air per gallon of waste treated. With a waste flow of 16 m.g.d., the aeration period is 80 min. based on the total flow through the aerators. Rate of sludge return is 35 per cent. The suspended solids in the mixed liquor are maintained between 1,000 and 1,500 p.p.m. with a sludge index of 50. The plant oxidizes 4 lb. of 5-day B.O.D. per 1,000 cu. ft. of air. This is equivalent to 67 lb. of 5-day B.O.D. per 1,000 cu. ft. of aeration capacity, or 250 cu. ft. of air per pound of B.O.D. satisfied. The aeration efficiency (pounds oxygen demand satisfied per pound oxygen blown × 100) varies from 16 to 22 per cent.

It should be emphasized that the above data are in terms of B.O.D. satisfied, instead of *removed*, because the activated sludge process in sewage treatment is a method of removing B.O.D., but not a process of complete oxidation, as some of the load is transferred, via the waste activated sludge, to the digesters for final destruction.

The experiment at Gary demonstrated the feasibility of treating ammonia still wastes by the activated sludge process. However, the conclusions drawn by Mr. Mathews in regard to mixed liquor solids concentration and air requirements are open to question until definitely proven. In view of the experiences at Midland, the writer must disagree with him. However, much can be learned from experiments in the laboratory, and it is hoped that Mr. Mathews can continue his good work and that all can share in his future findings.

# INDUSTRIAL WASTE GUIDE—BEET SUGAR

By Hayse H. Black and Gerald N. McDermott

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In 1948, beet sugar was produced at 85 plants operating in 16 states. California, Colorado, and Idaho were the three largest producers. A total of 1,369,000 tons of beet sugar were produced from 9,422,000 tons of beets, which represented 12.34 per cent of the world total. Liquid wastes from the beet sugar industry in the United States are conservatively estimated to have a population equivalent potential of 17,000,000, based on B.O.D.

## Description of Process

The process for extracting and refining sugar from beets is basically the same in all beet sugar factories. In 1946, there were 41 Steffen and 40 straight house plants operating in the United States. Beet sugar manufacture is seasonal, as there is no practical method of storing beets for long periods of time. The season begins as early as May 1 in the Imperial Valley (California), late July to September in other California areas and the Northwest, and about October 1 east of the Rocky Mountains. The season lasts 60 to 100 days. Operation is continuous throughout 24 hr. per day. The capacities of beet sugar factories are measured in tons of beets processed per day, plants varying in capacity from 1,000 to 5,900 tons.

### *Standard Beet Sugar Manufacture*

The beets are dug and topped both by machine and by hand. In those areas where cold weather requires early harvesting, the beets are stored in open piles. They are hauled by truck or train to the factory as needed. Figure 1 is a simplified flow diagram showing basic operations of a beet sugar factory. Both straight and Steffen house operations are included.

Beets are conveyed from the railroad cars or the storage area to the plant by means of water flowing in flumes. Devices for removing remaining beet leaves, floating debris, sand and rocks, and a controller for evening out the flow of beets, operate along the flume. Transportation of the beets in water in this manner washes most of the sand and soil from them. The beets are discharged from the flume to a beet wheel, which elevates them to a washer. The water passes on through the wheel to the plant sewer or flume-water recirculating system.

The washers are vat-type rectangular chambers, equipped with agitators. Fresh water is admitted and waste water released continuously. Some installations provide a final spray wash of the beets on a conveyor following the washer. Washed beets at some factories are passed over a picking table where spoiled beets and foreign material are removed by hand. Washer waste water is frequently passed through coarse screens to recover small pieces of beets and roots for stock food.

The washed beets are elevated to a weighing apparatus. From the scales they fall to slicers, where they are pressed against sets of rotating knives, which cut them into long narrow ribbons, V-shaped in cross-section, called "cossettes." The cossettes are transported on conveyor belts to the diffuser for extraction of sugar.

Most plants are equipped with the cell-type battery, although some of the

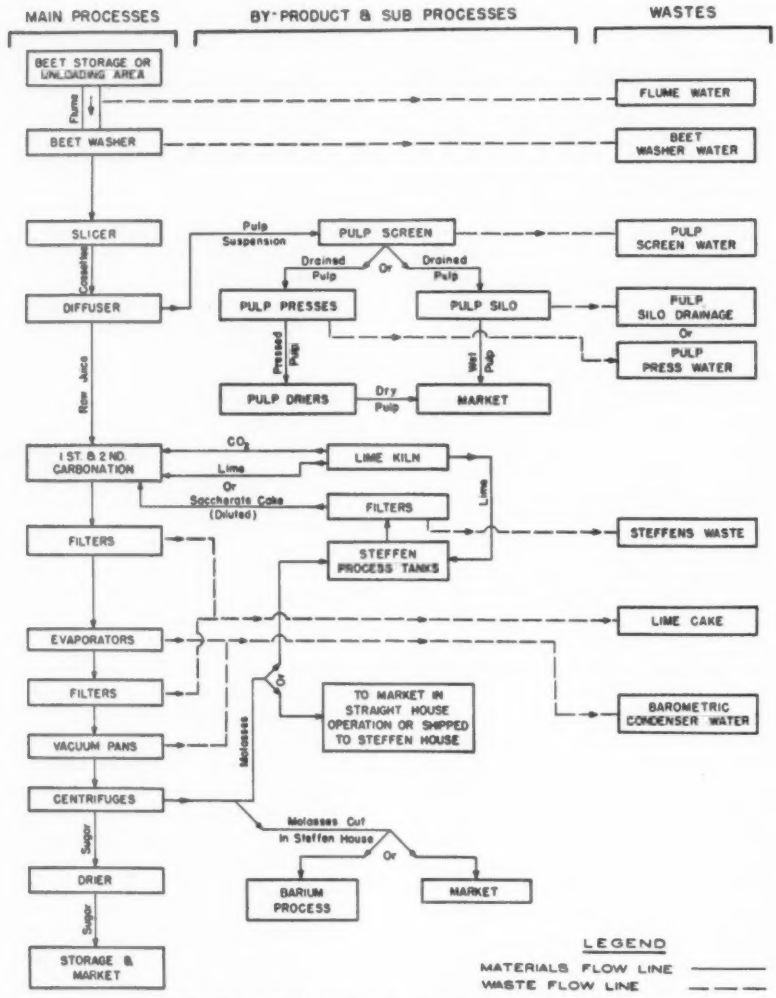


FIGURE 1.—Typical flow diagram of beet sugar factory.

more modern plants employ continuous diffusers. The cell-type battery consists of a series of 10 to 14 vertical cylindrical steel tanks, each of which holds 3 to 7 tons of cossettes. Sugar is extracted by passing hot water through the cossettes, employing the counterflow principle. These cells are connected by an intricate piping system so as to permit the diffusion liquor to pass progressively from one cell to the next in series. The cells are filled with cossettes in rotation and dumped of spent cossettes in similar sequence. Fresh battery supply water enters the cell containing cossettes which have

been longest in the system and from which, therefore, most of the sugar has been extracted. The water then passes progressively through cells which have been under diffusion shorter periods of time and leaves the battery after passing through the cell which has been most recently filled with cossettes. Three cells are usually out of circulation for dumping and filling operations. The liquid drawn from the diffusion battery is known as "raw juice." It contains 10 to 13 per cent sugar and both soluble and insoluble non-sugars.

Cells containing spent cossettes (pulp) are isolated from the circulating system and the contents dumped through a quick-opening gate. The gate may be located either at the bottom center of the cell or on the side of the cell adjacent to the bottom. Adhering pulp and that retained on cossette chain supports is flushed from the cell by battery wash water from a high-pressure hose. The side-dump type requires considerably more water for flushing than does the bottom-dump type.

The pulp, water contained in the cell when it is dumped, and battery wash water are collected in a flume running the length of the battery. This pulp suspension is pumped over a screen, frequently of the "A-frame" type. A large portion of the water drains from the pulp through the screen.

This pulp constitutes high-grade stock food. At some factories the pulp is stored in the wet state (that is, as drained on the screen) pending feeding. Wet pulp is stored in open pit silos provided with an underdrain system. At other factories, screened pulp is further dewatered in special presses and promptly dried to about 12 per cent moisture in rotary kilns, usually of the direct-heat or fire-drier type.

Several types of continuous diffusers are in use, most of which have been recently developed and perfected. Although the types differ considerably in design, all employ the principle of countercurrent flow by mechanically moving the cossettes in reverse direction to the flow of diffusion liquor. In continuous diffuser operation the pulp is delivered from the diffuser in a drained state. At some factories water is deliberately added to the pulp from continuous diffusers in order to form a water suspension that can be pumped to the silo. Use of conveyor belts to transport drained pulp to presses or a silo obviates the need for screening, thus eliminating pulp screen water waste.

The raw juice from the diffusion process is subjected to chemical treatment and filtration, which removes a large percentage of suspended matter and 30 to 40 per cent of the non-sugars. In straight house operation, milk of lime is added to the raw juice and carbon dioxide, produced in a lime kiln from limestone and coke, is bubbled through the limed juice. In Steffen house operation, calcium saccharate, from the Steffen process described later, is added to the raw juice instead of milk of lime. The precipitate which forms when the juice is limed and carbonated is filtered or settled from the juice. The juice is carbonated a second time, refiltered, and then treated with sulfur dioxide gas and filtered a third time. The material removed by this process is known as lime cake. It is diluted with water and discharged as a slurry.

The partially purified juice is concentrated in multiple-effect evaporators and filtered again. Sugar is recovered by further evaporation of water in vacuum pans to the point where sugar crystals of the desired size have formed. The sugar crystals are separated from the liquid by centrifuging. The residual syrup is further evaporated and centrifuged a second time, and finally a third time. Sugar from the second

and third crystallizations, being impure, is remelted and returned to the process for recovery in first crystallization. In straight house operation, the resulting molasses following third crystallization and centrifuging is shipped to a Steffen house for additional sugar recovery, or is marketed. The most important commercial uses of beet sugar molasses are yeast manufacture, alcohol production, and as stock food supplement.

Beet sugar molasses normally run about 82 per cent dry solids, of which 60 to 63 per cent are sugar. In other words, every pound of non-sugar which is not removed in either the diffusion or carbonation processes goes into molasses and takes with it 1.5 lb. of sugar. The Steffen process is employed when the additional sugar recovered is of greater value than the molasses and the expense of recovery.

In the Steffen process, molasses from the third centrifuging is diluted and lime is added under carefully controlled conditions. This lime treatment produces a calcium saccharate precipitate, which is removed from the dilute molasses by filtering. Some Steffen houses heat the cold filtrate to approximately 85° C., thereby precipitating more calcium saccharate, and recover it with a second filtration. The filtrate is known as Steffen waste. The saccharate cake contains, in addition to sugar, both soluble and insoluble non-sugars. It is diluted to a saccharate milk and used for raw juice purification immediately prior to carbonation.

Sugar returned in the saccharate cake is recovered by conventional straight house operation. Non-sugars returned to the process with the saccharate cake become increasingly concentrated in the molasses as the process continues. In order that these non-sugars do not interfere with economical sugar recovery, a portion, or cut, of the third centrifuge molasses is drawn off. Molasses produced at other straight houses (foreign molasses) is processed by most Steffen houses as a means of alleviating the detrimental effect of accumulation of inseparable non-sugars.

The third centrifuge molasses discard, essential in most Steffen houses, is usually marketed. However, it is possible to extract even more sugar as a barium saccharate. One barium extraction plant is in operation in the United States. The end liquor from this barium extraction plant is incorporated with dried pulp for stock feed.

### *Ion Exchange Process for Beet Juice*

Recent development of the organic or resinous type of ion exchangers provides a means for increasing the efficiency of removal of non-sugars from second carbonation beet juice prior to evaporation and crystallization (1). The end result is increased sugar yield, a substantially reduced molasses production, and a molasses that can be converted by further ion exchange treatment into an edible product (1) (2).

The cation exchanger is a granular sulfonated phenol formaldehyde resin possessing the property of exchanging hydrogen ions present in its structure for cations (such as sodium, potassium, calcium, magnesium, and organic cations) when in contact with solutions of these salts. The hydrogen ions replace the cations in the solution, forming the acids of the various anions. The anion exchanger, or acid adsorber, is a polyamine phenol formaldehyde resin having the capacity to molecularly adsorb or possibly to exchange hydroxyl ions for the anions found in acid-bearing solutions (1). Consequently, when a sugar solution containing dissolved salts is passed through a bed of cation exchanger, then through a bed of acid adsorber resin, the resulting solution is essentially free of ionizable salts.

**TABLE I.—Representative Values of Character and Volume of Beet Sugar Manufacturing Wastes**

| Waste | Flow, per Ton of Beets (gal.) | B.O.D., 5-Day, 20° C. (p.p.m.) | Susp. Sol. (p.p.m.) | 5-Day B.O.D., per Ton of Beets Sliced (lb.) |
|---|---|---|---|---|
| Flume water | 2,600 | 210 | 800–4,300 | 4.5 |
| Pulp screen water: | | | | |
| Bottom dump cell-type diffuser | 240 | 980 | 530 | 2.0 |
| Side dump cell-type diffuser | 1,420 | 500 | 620 | 5.9 |
| Continuous diffuser[1] | 400 | 910 | 1,020 | 3.0 |
| Pulp press water | 180 | 1,710 | 420 | 2.6 |
| Pulp silo drainage | 210 | 7,000 | 270 | 12.3 |
| Lime cake slurry | 90 | 8,600 | 120,000 | 6.5 |
| Lime cake lagoon effluent | 75 | 1,420 | 450 | 0.89 |
| Barometric condenser water | 2,000 | 40 | | 0.67 |

[1] Water-transported pulp in lieu of mechanical conveyor.

Relatively strong sulfuric acid solution is used to regenerate the cation resins. The anion resins are regenerated by washing with an alkali solution composed of sodium hydroxide and ammonia. After the excess regenerants are washed from the resin beds, they are virtually recovered to their original capacity. Three beet sugar refineries in the United States are known to be using ion exchange for treatment of all or a part of sugar beet juices (3).

## Raw Materials and Products

### *Raw Materials*

Raw materials for the processing of 1 ton of sugar beets are approximately as follows:

| | |
|---|---|
| Sugar beets | 1 ton |
| Limestone | 60–135 lb. |
| Coke | 5–11 lb. |
| Coal | 180–280 lb. |
| Sulfur | 0.5 lb. |
| Water | 2,500–3,500 gal. |
| Diatomaceous earth filter aid | |
| Sodium carbonate | |

Coke is burned in a kiln with the limestone to produce lime and carbon dioxide. Considerably more lime per ton of beets is required in the Steffen house than in the straight house. Coal is used for steam production and for pulp drying. Natural gas may also be used.

### *Products*

Sugar beets vary considerably in sugar content, ordinarily ranging from 12 to 18 per cent. Sugar yield depends upon the processes employed; that is, whether or not the Steffen and barium processes are included. One ton of beets yields from 200 to 300 lb. of refined sugar. Straight house operation extracts 80 to 85 per cent of the sugar from the beet. The Steffen process extracts an additional 10 per cent.

In addition to refined sugar, a number of by-products are produced. Pulp is an important by-product for stock feeding. One ton of beets yields about one ton of wet pulp (95 per cent moisture), or about 110 lb. of dried pulp (12 per cent moisture). Molasses production from straight house operation is governed by the quality of the beets processed. The quality of beets is dependent, in turn, on the region in which they are grown. Beets from the Rocky Mountain area yield about 75 lb. of straight house molasses per ton of beets, whereas those from Ohio, which contain a higher percentage of extractable non-sugars, may yield 120 lb. Lime cake is used as fertilizer in certain areas.

Steffen waste from some Eastern and California factories has been processed in recent years for recovery of monosodium glutamate, a taste-intensifying

TABLE II.—Steffen Waste Character and Volume

| Waste | Flow, per Ton of Molasses[1] Processed (gal.) | B.O.D., 5-Day, 20° C. (p.p.m.) | Susp. Sol. (p.p.m.) | 5-Day B.O.D., per Ton of Molasses Worked (lb.) |
|---|---|---|---|---|
| Steffen | 2,640 | 10,500 | 100–700 | 231 |

[1] Converted to 50 per cent sucrose (sugar) basis.

condiment (4). The waste also contains valuable fertilizer components, which were successfully recovered during their high-value period of World War I.

## Volume and Character of Wastes

Values considered to be representative of the volume and character of beet sugar manufacturing wastes are given in Tables I and II. Cognizance must be taken of differences in process equipment and other pertinent factors in selecting and applying the values for estimates of waste volume or character at any factory. Detailed discussion of each of the wastes is presented in subsequent paragraphs.

### *Flume Water Waste*

Flume water waste comprises the water used in floating beets from storage or unloading areas to the factory and the waste from the beet washer. It contains large quantities of soil washed from the beet, pieces of beet roots, leaves, trash, and a small quantity of materials in solution. The characteristics depend considerably on the type of soil in which the beet is grown, the nature of the weather during harvest, and the extent of spoilage in the stockpile. Wet weather during harvest may be expected to increase the quantity of soil and silt carried on the beets. One investigator found certain characteristics of this waste to triple in value over the season due to freezing and deterioration of the beets (5).

Suspended solids are most variable, with values as high as 4,300 and as low as 800 p.p.m. having been observed. Flume water B.O.D. normally varies between 150 and 250 p.p.m., but may triple in concentration when transporting frozen or rotten beets. The volume of flume water at different factories ranged from 2,100 to 3,100 gal. per ton of beets.

### *Pulp Screen Water*

The pulp screen water is drained from the pulp through a screen. It is comprised of water contained in each cell when it is isolated from the diffusion circuit for dumping, plus water used to flush out the cells, and, in certain cases, water added to create a pulp suspension for pumping to the screen. It contains finely divided pulp in suspension, organic material in colloidal suspension, and a comparatively large amount of sugar and other organic material in solution. The sucrose content has varied between 300 and 600 p.p.m. A small amount of sand from the beets is also present. The amount of pulp present is dependent on the fineness of the screen. This waste has a temperature of about 50° C.

The concentration of the waste is dependent to a considerable extent on the type of diffuser and the efficiency of the pulp screen. Diffusers requiring large volumes of wash water give a relatively dilute waste, but the over-all pollution load is increased. The B.O.D. varies between 500 and 1,000 p.p.m., depending on the type of diffuser. The B.O.D. of daily composites may vary as much as 50 per cent from the average. Pulp screen water from one plant with bottom dump diffuser cells had an average 5-day B.O.D. of 980 p.p.m. following screening through a 30- by 40-mesh vibrating screen.

### *Pulp Press Water*

At factories where pulp is dried, the screened pulp is further dewatered in presses before drying. The water

pressed from the pulp constitutes pulp press water. The characteristics of pulp press water vary with the physical quality of the pulp. They are similar to pulp screen water with somewhat higher solids and B.O.D. The sucrose content may average as much as 2,100 p.p.m. Pulp press water amounts to some 180 gal. per ton of beets, with a B.O.D. averaging 1,700 p.p.m.

*Pulp Silo Drainage*

Pulp silo drainage liquor drains from wet pulp during storage in open silos. The volume varies with the quantity of pulp stored, efficiency of the pulp screen, fermentation, and rainfall. The volume per ton of beets at two factories averaged 165 and 270 gal., respectively. Daily flow varied as much as 30 per cent from these average values. The B.O.D. of these same wastes averaged 8,800 and 6,000 p.p.m., respectively, with daily composites varying as much as 50 per cent from the averages. Organic acids of decomposition create a pH of about 4 in this waste.

Pulp silo drainage is the one waste which does not cease at the end of factory operation. In fact, it may become stronger if pulp remains in the silo until warm weather. Data given in Table I for silo drainage are for the period the factories were operating (6).

*Lime Cake Slurry*

Lime cake forms when lime-treated and carbonated juice is filtered. It is common practice to dilute the cake with water to form a slurry which can be pumped. The amount of water added to the cake is dependent to some extent on the type of filter and the operator. These factors must be considered in comparing volumes and concentrations of the waste. Lime cake waste has been reported to average from 6,850 to 10,250 p.p.m. B. O. D. and 107,000 to 137,000 p.p.m. suspended solids. The pH of the waste is about 11.7.

The pollution load per ton of beets in this waste is greater for a Steffen house than for a straight house. Available data indicate a B.O.D. load of 8.2 lb. per ton of beets for Steffen house, as compared to 4.3 lb. for straight house lime cake slurry. This indicates materials return with the saccharate from the Steffen process which are removed in the lime cake. Accepting this premise, it will be evident that lime cake waste from a Steffen house will be influenced by the amount of molasses worked.

*Steffen Waste*

The filtrate produced in filtering saccharate cake from lime-treated diluted molasses in the Steffen process is known as "Steffen Waste." Because Steffen plants process varying amounts of foreign molasses in addition to their own, it is desirable to express Steffen waste on the basis of molasses worked. Steffen waste is reasonably uniform in volume and concentration, as will be appreciated from the following considerations.

Beet sugar molasses contains 60 to 63 per cent sucrose (sugar), dry solids basis. This relation between sugars and non-sugars holds whether the molasses is produced in a straight house or a Steffen plant. On a total weight basis, molasses is about 50 per cent sucrose. It is customary in the industry to convert molasses to a 50 per cent sucrose basis, which likewise reduces the non-sugars to a common basis.

In Steffen house operation, the calcium saccharate returned to process carries with it inseparable non-sugars. These non-sugars tend to accumulate in the Steffen house molasses and, if not eliminated from the system, eventually interfere with sugar crystallization and refining. A fair degree of uniformity in molasses worked by the Steffen process is achieved by correlat-

ing the amount of foreign molasses intake with Steffen molasses marketed.

Approximately 11 tons (2,640 gal.) of Steffen waste are produced for each ton of molasses worked. The waste is high in total solids (25,000 to 40,000 p.p.m.), almost all of which are in solution. A good average value for 5-day B.O.D. appears to be 10,500 p.p.m. The pH may be as high as 12.6. These data apply to Steffen plants employing the combination, cold and hot, saccharate process.

*Barometric Condenser Water*

Barometric condenser water comes from the multiple-effect evaporators and vacuum pans. This waste is comparable to flume water in volume, but is relatively low in pollutional material. Entrainment from the last effect varies with evaporator design and operation. Evaporator condensates not re-used in process and heated water from other sources may be discharged along with barometric condenser water. Data obtained on the volume and character of condenser water are given in Table I. Evaporation of Steffen waste produces additional condenser water.

*Ion Exchange Regenerant Wastes*

There are no known data showing the volume and characteristics of the acid and alkaline wastes from regeneration of ion exchange resins. Obviously, these wastes will contain the non-sugars which would normally be found in Steffen waste. It would appear that the pollution load for a beet sugar refinery employing ion exchange treatment of second-carbonation juice should resemble the waste from a Steffen plant more closely than from a straight house.

The ion exchange cation and anion beds are regenerated simultaneously. This practice tends to neutralize the combined discharge. However, excess acid and alkali are to be expected in the regenerant wastes.

*Miscellaneous Wastes*

Other wastes of a comparatively minor nature are those from washing filter cloths, equipment, and floors, and from the testing and control laboratory. Sanitary sewage should be separated from process wastes.

## Pollutional Effects

Liquid wastes from manufacture of beet sugar are similar to those from other food processing industries. Oxygen depletion and sludge deposits are common damages to the receiving waters. Destruction of normal aquatic life and severe odor nuisances have resulted from promiscuous discharge of these wastes. The high lime content of beet sugar wastes may impart sufficient hardness to the water to be detrimental to its subsequent use. Relatively high-temperature waste, such as barometric condenser water, may raise the temperature of the stream, thereby decreasing its oxygen carrying capacity as well as encouraging growth of "sewage fungus."

## Remedial Measures

Although several methods for abating pollution have been developed and applied on plant scale, there is no unanimity of opinion in the industry regarding the preferred approach. Concerted effort is being made to solve these waste problems through changes in process, rather than to install costly waste treatment systems. Remedial measures which have proven successful in varying degrees include: elimination, segregation and re-use, by-product recovery, and waste treatment as a last resort.

*Elimination*

1. Pulp screen water.—This waste can be eliminated by the continuous diffuser, together with a mechanical conveyor, which will transport the drained pulp from the diffuser to the

presses. This precludes the practice at some plants of deliberately diluting the pulp so that it can be pumped as a suspension. Although the great majority of existing plants employ the cell type diffuser, the trend in new construction and remodeling is toward the continuous diffuser.

2. Pulp silo drainage.—Discharge resulting from storage of wet pulp in open pits has proven a major pollution source. Prompt pressing and drying of the pulp not only eliminates this waste, but also substantially increases the yield of beet pulp cattle food. The pulp press water which is produced introduces another problem but of greatly reduced magnitude.

*Segregation and Re-Use*

Recirculation and re-use hold considerable promise of economical solution to several of the most important beet sugar wastes. The ever-present danger of serious process interference has been a deterring factor to re-use. However, during recent seasons valuable plant operation data have been obtained which seem to favor re-use as a method of handling the major wastes.

1. Flume water.—Recirculation of flume water is being successfully practiced at a number of plants (7)(8)(9). Screening and plain sedimentation provide clarification satisfactory for re-use. Some factories use short-time detention basins equipped with sludge removal mechanisms; others pass the waste through a lagoon, in which settleable solids are allowed to accumulate. The sludge concentration as pumped from the settling basin may be as low as 1.5 per cent solids, of which about 25 per cent are organic. The amount of silt adhering to the beets depends very largely on the type of soil in the beet producing area and on weather conditions prevailing during harvest.

Soluble solids and finely divided material build up in the recirculated water. Following stabilization of operation, effluent from the sedimentation basin has been observed to have a total solids concentration of 0.5 per cent and a 5-day B.O.D. of 1,300 p.p.m. Some operators have reported offensive odors developing in recirculated flume water. Intermittent chlorination of flume water has proven effective in controlling these odors. Clean water taken into the system to offset that removed with the sludge tends to keep the flume water fresh.

2. Pulp screen water and pulp press water.—These wastes have been used as diffusion battery water supply for some time by European factories and more recently in certain United States plants (10)(11)(12)(13)(6). The greatest single impelling force for re-using pulp screen and pulp press water is stream pollution abatement. Numerous advantages are claimed and several possible disadvantages are recognized. The proposal continues to be controversial, with favorable reports apparently predominating.

Advantages claimed for re-use as diffusion water are:

a. Recovery of sugar and pulp.
b. Conservation of heat.
c. Reduction in fresh water required.
d. Economical method of waste disposal.

Possible disadvantages to re-use which have been cited include:

a. Suspended matter might obstruct flow around cossettes.
b. Interference with diffusion of sugar from beets.
c. Increase in non-sugar might retard crystallization.
d. Detrimental effect of thermophilic organisms.

Treatment of these wastes prior to re-use as diffusion battery water includes efficient removal of suspended solids and destruction of thermophilic bacteria. Suspended solids have been effectively removed by screening

through a 30- by 40-mesh vibrating screen. Plain sedimentation likewise has been reported as satisfactory. Thermophilic organisms in the diffusion water, if not controlled, produce objectionable odors, invert sugar, cause gas binding in the diffuser, and create low pH conducive to corrosion. Chlorination and heat treatment have both been successfully employed on plant scale. The efficacy of lime treatment has been demonstrated in a pilot plant.

Although efficient removal of suspended solids from these wastes is deemed advisable prior to re-use as diffusion water, plants have been operated with inadequate screening and very short retention periods. The literature records one factory returning water from the pulp screen, following chlorination, directly to the diffusion battery supply. The most obvious operating difficulties resulting from inefficient solids removal were clogging of return pipe lines and excessive chlorine demand. The very fact that reasonably satisfactory diffusion is possible under these adverse conditions tends to discount some of the concern associated with re-use.

Plant-scale studies with chlorine treatment indicate that chlorine dosages of 25 to 60 p.p.m. in the pH range of 5.5 to 7.0, followed by sedimentation, permit satisfactory re-use of pulp screen and pulp press water as battery water supply (14). The chlorine was reported to produce some flocculation with improved clarification. The chlorine dosage is influenced by the contact time and solids concentration of the recirculated water. The total solids concentration in recirculated water at one plant was 8,750 p.p.m. at the end of the season.

Lime or acid treatment and sedimentation of these waste waters may be expected to remove a large percentage of the suspended solids. Acid treatment of pulp press water preliminary to re-use is reported widely practiced in Sweden (11). The literature reports that recovery of sugar was not affected by re-use of pulp screen and pulp press water in 15 Swedish factories. Certainly there is a potential recovery of additional sugar. Sugar contained in the waste water re-introduced into the system should appear either as increased sugar yield or in the molasses. This theory is based on normal sugar losses in other factory wastes.

In one plant, pulp press water was heated to 73° to 75° C. and added to the battery supply tank, where it was mixed with fresh water and a temperature between 60° and 65° C. was maintained. No deleterious bacterial activity was observed. These temperatures attain the best balance between pulp losses, water introduced to the battery, and pulp press work. It would be possible with continuous diffusers to introduce pulp waters a short distance ahead of the point where spent cossettes are withdrawn. This procedure would minimize solids build-up in the re-used water, inasmuch as the re-used pulp water is purged from the pulp by fresh water prior to the pulp leaving the diffuser.

The re-use of pulp screen water and pulp press water is not limited to use in the diffusion process. A portion of these wastes may be used to make the lime cake slurry. Likewise, a portion may be used to dilute molasses in the Steffen process. In this operation, the pulp water may be treated with lime and settled prior to mixing with the molasses. This produces another sludge, which must be dealt with. If not treated before such re-use, the precipitated material will appear in the lime cake wastes of raw juice purification. In either case, soluble impurities are transferred to the Steffen waste.

Elimination of wastes by re-use of pulp and pulp press water is qualified by the transfer of non-sugar pollutants to other factory wastes. Maximum effectiveness of such re-use will be

achieved only by application of remedial measures to all wastes concerned.

3. Lime cake.—A number of foreign plants were reported calcining the lime cake and re-using the lime. Lime make-up was reported as 25 per cent, indicating some discard. Reburning of defecation lime cake in a multiple-hearth furnace at one California plant was reported to produce calcium oxide of exceptionally good quality for Steffen house operation (15). Burning of the lime cake would encourage handling it in the comparatively dry state as removed from the filter presses. The cake contains about 50 per cent moisture and can be handled by belt conveyor or other mechanical means. The practice of diluting lime cake to a slurry is an expedient to handling.

4. Barometric condenser water.—It is common practice to re-use barometric condenser water or condensates for fluming and washing beets, for diffusion battery water, for washing lime cake, for dilution of lime cake, for cleaning filters, and for boiler feed. The pollutional effect is thus transferred to other factory wastes.

At some beet sugar factories in England this barometric condenser water is cooled and re-used in the barometric condensers. Growth of bacteria and fungi in cooling towers is controlled by chlorine treatment (8).

*By-Product Recovery*

By-products from beet sugar manufacture are confined to molasses, beet pulp, and recovery from Steffen waste. Information pertaining to pulp and molasses is given in a previous section designated "Products."

The most promising solution to the Steffen waste problem is to concentrate the material in multiple-effect evaporators and to incorporate the syrup with the beet pulp, thereby enhancing its nutrient value. Experimental work has been conducted with both evaporation and feeding of the enriched beet pulp. Results of this research show promise of profitable by-product recovery.

Monosodium glutamate is currently being produced at plants in California and Ohio. This process uses the Steffen waste, which has been concentrated to between 60 and 70 per cent total solids, and produces glutamic acid by caustic hydrolysis, acid treatment of the hydrolysate, refining, and crystallization. The end liquor from the monosodium glutamate process has a solids concentration of 65 per cent and a 5-day B.O.D. of 378,000 p.p.m., a formidable waste. Studies are being made with the view of incorporating this end liquor with the beet pulp as a fortifier for the pulp stock food.

Steffen waste also possesses potash and nitrogen constituents in concentrations inviting recovery. During World War I, recovery of these constituents proved economically sound (4).

*Individual Wastes Treatment*

Considerable research has been conducted in the treatment of beet sugar wastes, both individual and combined. Seasonal operation causes overhead to be costly for treatment of the wastes as produced.

1. Flume water.—Treatment consists of screening, grit removal, sedimentation with or without coagulants in tanks equipped for continuous sludge removal, and either vacuum filters or sludge ponds. A retention of 80 min. in the sedimentation basin has been recommended. Removals by this treatment have been reported as high as 92 per cent suspended solids and 42 per cent 5-day B.O.D. (16). Steffen waste has been reported satisfactory as a coagulant for flume water (17).

2. Lime cake slurry.—This waste is commonly stored in ponds providing several days detention. Such treat-

ment removes practically all of the suspended solids and gives a substantial reduction of B.O.D. The volume of this waste is such that lagooning for the entire season is feasible.

3. Pulp screen water and pulp press water.—Even though re-use of this process water as diffusion battery water supply should be generally accepted, such a process modification will be gradual in the industry and these wastes must be reckoned with in the interim. Fine screening materially reduces the concentration of these wastes and yields quantities of pulp having economic significance. Vibrating screens (30- by 40-mesh) have been successfully employed. This type of screen has a capacity for screening 22 gal. per square foot per minute of the combined process wastes.

Coagulation of pulp screen and pulp press water with lime has been practiced, using a dosage of 500 to 600 p.p.m. CaO. Lime treatment requires a chemical feeder, mixing chamber, coagulation tank, sedimentation basin, and sludge disposal facilities. Coagulation for 20 to 30 min. and a settling period of 2 hr. has been recommended. Such treatment produces a water-clear effluent and B.O.D. reductions as high as 47 per cent are reported. Other studies have shown as low as 30 per cent average 5-day B.O.D. reduction for lime treatment. In any event, the effluent is still highly objectionable, in that the B.O.D. remaining is high and the treated waste is caustic, containing considerable calcium.

*Combined Wastes Treatment*

The most optimistic results through elimination, re-use, and by-product recovery will still leave miscellaneous wastes, discharge from recirculation systems, and lagoon supernatant requiring treatment except in those locations where there is adequate dilution in the receiving stream.

Lagooning has been used as an expedient for handling wastes from beet sugar manufacture (18). Some natural purification is accomplished over a period of several months. Except in arid regions, the ultimate objective in lagooning is to dispose of the partially purified wastes by controlled dilution during periods of high stream discharge and low water temperatures. The most significant objections to lagooning as a means of disposing of beet sugar wastes are:

1. Potential pollution hazard from major seepage or dike break.
2. Large lagoon areas, which frequently give off obnoxious odors.

The British Water Pollution Research Laboratory has reported satisfactory pilot plant treatment of lagooned beet sugar wastes by biological filtration (19). Experimental work was performed with recirculated flume water containing about 2 per cent process wastes (pulp screen and press water) at both standard and high-capacity rates. The experimental filter was 12 ft. in diameter and 6 ft. deep.

This experimental work demonstrated that settled flume water was amenable to biological filtration and that this treatment could be relied on to consistently give a treated waste with a 5-day B.O.D. less than 20 p.p.m. The British concluded from this research that, if settled waste waters were treated continuously throughout the year, a biological filter 60 ft. in diameter and 6 ft. deep should be adequate for treating residual wastes from a factory slicing 2,000 tons of beets per day (8). This system still requires extended storage of a large volume of waste.

## Consideration for New Plant

It is a relatively simple matter to plan for segregation and re-use of process water in design of a new plant or in modernization of an existing factory. Likewise, by-product recovery

may be more readily incorporated into new design. The potentials of increased sugar yield, water conservation, and heat economies can be exploited to the maximum. Those factors having bearing on wastes should be coordinated with requirements of established objectives and subsequent stream use.

## Acknowledgments

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# VOLATILE ACID PRODUCTION DURING DIGESTION OF SEVERAL INDUSTRIAL WASTES *

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A study of volatile acid production during the digestion of seeded mixtures of industrial wastes might have a practical significance if it could be established that different modes of decomposition take place with the overloaded as with the normal digesting seeded mixtures. If decomposition of overloaded mixtures proceeded differently from the digestion with normal load, the extent of the change might be such as to retard recovery. It was shown in the digestion of seeded, limed, and improperly digesting seeded solids (4) that the mode of decomposition was not affected by the conditions of decomposition, but that the rate of hydrolysis was affected. Therefore, the extent to which an industrial waste mixture is overloaded might be important if the concentration or types of the various volatile acids changed significantly from the normal decomposing mixtures.

Another important factor to be considered is the possibility of by-product recovery.

In making a study of volatile acid production during the digestion of normal and overloaded seeded mixtures of various industrial wastes, the following wastes were selected:

1. Yeast.
2. Paper white water.
3. Slaughterhouse.

These wastes were of different composition and would be expected to produce different intermediate compounds. The yeast is rich in nutrients, the white water low in nitrogen content, and the slaughterhouse high in nitrogen. The purpose of the experiments reported herein was to acquire information as to the types and quantity of acids produced during the digestion of these wastes. In both the yeast and slaughterhouse waste studies, mixtures were intentionally overloaded so that a comparison could be made with the normal digesting mixtures as to type and quantity of volatile acids produced.

## Methods

A series of experiments was carried out in which concentrated spent yeast nutrient was seeded with acclimatized ripe sludge on the basis of three different volatile matter ratios and allowed to digest quiescently at 20° C. The three volatile matter ratios used were 1:20, 5.6:1, and 9.3:1, respectively, as yeast waste volatile solids to acclimatized ripe sludge volatile solids.

Determinations made and recorded were pH, solids, ash, gas volume, carbon dioxide in the gas, and individual volatile acids. Whenever possible, the Werkman partition analysis technique (2)(5) for the individual volatile acids was applied to the recovered acids. Where the partition analysis was not applicable, the Craig countercurrent distribution technique (1)(6) was employed. On occasion, the recovered acids were not present in sufficient concentration to allow application of either method of analysis; consequently, these samples were recorded as total p.p.m. propionic (2).

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The concentrated spent yeast nutrient waste was obtained, and the ripe sludge was acclimatized by adding increasing increments (2.5 per cent by volume) of yeast waste to ripe sludge until the daily loadings amounted to 12.5 per cent by volume.

A sample of white water was concentrated by evaporation and then added to ripe sludge on a 1:1 volatile matter basis. To this mixture was added $(NH_4)_2CO_3$ in sufficient concentration so that the nitrogen-carbon ratio was 1:40. A total of 24.35 g. of volatile white-water solids was taken for the digestion experiment and incubated at 20° C. The determinations made were pH, ash, solids, gas volume, gas composition, and individual volatile acids (2)(5).

Digestion experiments of slaughterhouse waste were conducted on three separate loadings in such a manner that additions and withdrawals could be made without introducing air. The raw waste was adjusted by dilution to an approximate B.O.D. of 1,500 p.p.m. based on oxygen consumed analysis of the undiluted waste using an average oxygen consumed-B.O.D. ratio of 4.3. For a period of 6½ days, additions of 500, 1,000 and 2,000 ml. of diluted waste were made twice daily to separate 500-ml. portions of slaughterhouse acclimatized ripe sludge. The analyses made on the diluted raw waste were B.O.D., pH, total solids, volatile solids, and total volatile acids; determinations made on the digested effluents were B.O.D., pH, total solids, volatile solids, suspended solids, total volatile solids, and individual volatile acids (1)(2)(5)(6). Gas measurements and gas analyses were also made.

All gas measurements were made from mixtures in sealed bottles, and the analyses performed on the yeast nutrient and white-water waste diges-

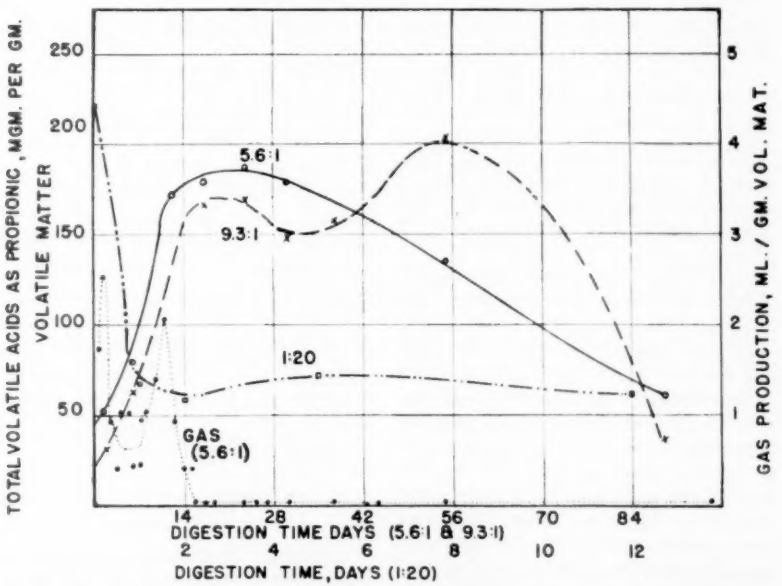


FIGURE 1.—Total volatile acid concentration in digestion of concentrated yeast nutrient waste in mixtures with various waste to ripe sludge volatile solids ratios.

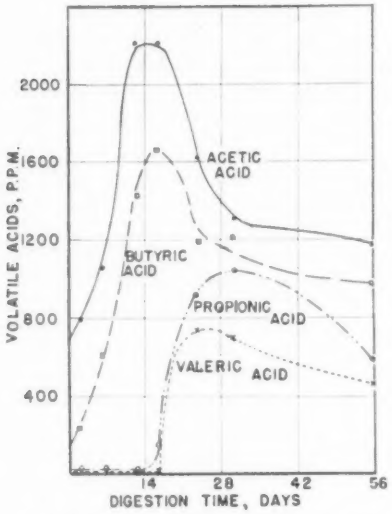


**FIGURE 2.—Individual volatile acid concentrations from digestion of 5.6:1 (waste to ripe sludge volatile solids ratio) mixture of concentrated yeast nutrient waste.**

tions were made on samples taken from duplicate carboys.

## Experimental Results

### *Spent Yeast Nutrient Waste*

The data obtained from the three separate digestion experiments on spent yeast nutrient waste are presented graphically in Figures 1, 2, and 3.

In Figure 1 the three different digestion mixtures are presented and compared on the basis of total volatile acid accumulation per gram of volatile matter. Both the 5.6:1 and 9.3:1 ratios behaved similarly during the first 41 days of digestion; the acid accumulation per gram of volatile matter was consistently lower during the first 41 days in the 9.3:1 overloaded mixture. Although these differences were consistent and definite, they were not appreciable. After reaching and remaining at its peak level for 41 days, the acid accumulation began to increase in the 9.3:1 mixture, reaching a peak on the 55th day. A possible explanation is presented later after other pertinent facts of gas production and individual acid accumulation are discussed.

Also in Figure 1, the total volatile acid accumulation in a normal yeast waste digestion (1:20 volatile matter basis) is shown in contrast to the results obtained with the overloaded mixtures. Although the abscissa time scales of the normal and overloaded digestions are different, the ordinate scales of acid accumulation per gram of volatile matter taken are identical; consequently the contrasts are effectively shown. The normal digestion showed no acid accumulation, but a sharp drop in acid content to a constant low level. In previous experiments (4), properly seeded fresh solids gave identical results.

The accumulation of individual acids as digestion progressed in the 5.6:1

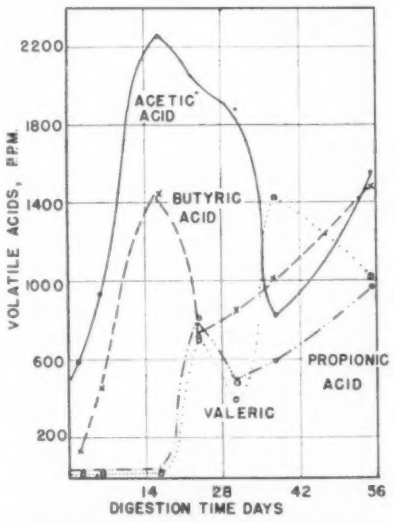


**FIGURE 3.—Individual volatile acid concentrations from digestion of 9.3:1 (waste to ripe sludge volatile solids ratio) mixture of concentrated yeast nutrient waste.**

mixture is shown in Figure 2. Four separate volatile acids were found in measurable amounts. During the first 16 days of digestion, only acetic and butyric acids were found. After 16 days, both propionic and valeric acids appeared in appreciable quantities, in addition to the acetic and butyric acids. To determine the four-acid mixtures, the Craig countercurrent procedure (1) (6) was used only after the Werkman method (2) (5) was found ineffective. A sample for volatile acids determination was available after 89 days, but it had such low concentration that it was all consumed during the partition method analysis. This partition analysis indicated the presence of a higher volatile acid, probably valeric, but proof was not possible. The lower total volatile acids (1,505 p.p.m. as propionic) obtained with this last mixture as compared with the previous analysis (3,185 p.p.m.) indicates that the acids present were decomposing readily and the curves of Figure 2 would continue to decrease uniformly. Neither propionic nor valeric acids appeared until maximum total acid accumulation occurred. It is possible that these two acids are indicative of an overloaded yeast waste digestion.

In Figure 3 are presented the individual acid accumulations during the digestion of the 9.3:1 mixture. Again, for the first 23 days of digestion, the acid trends were similar to those in the 5.6:1 mixture; both the propionic and valeric acids did not appear until maximum acid accumulation had taken place. After 23 days of digestion the acid composition took an unusual trend. Both the propionic and valeric acids began to decrease in concentration, with a corresponding increase of butyric acid accumulation and a decrease of the rate of acetic acid decomposition. This would indicate a conversion of propionic and valeric acids to acetic and butyric. Suddenly, all the acids present began to increase in concentration. This sudden increase remains unexplained; no such action took place with the 5.6:1 mixture.

As in the 5.6:1 mixture, the final sample from the 9.3:1 mixture decreased to a low total volatile acid content of 937 p.p.m. No aliquot was available for a Craig analysis. The Werkman partition indicated the presence of a higher volatile acid, probably valeric.

Gas production decreased as soon as the acids reached their maximum level. Apparently the reaction became so unfavorable that little or no decomposition took place after the acid accumulation reached the maximum level.

Referring again to Figure 1, in which the total acids present in the digestion mixtures at various intervals of time are shown graphically, the drop in total acids in the 5.6:1 ratio after the 30th day did not result in a corresponding increase in gas production. In fact, no gas production occurred and acid decomposition continued through the 92nd day. It would seem that acid decomposition should be accompanied by gas production. The pH within the carboys from which samples were drawn for analysis differed somewhat from that of the sample connected to the gasometer. After 92 days the seal was broken on the gasometer-connected digestion mixture and the pH recorded was 5.6, whereas the carboy samples measured a pH of 5.62 after only 44 days. After 55 and 89 days the carboy samples recorded pH values of 6.0 and 6.9, respectively. It is apparent that with such large deviations of pH values, similar reactions in the gasometer and in the carboys would not occur. Consequently, it may be assumed that gas production had occurred during the acid decomposition of the 5.6:1 ratio digestion mixture in the carboy, although none occurred with the gasometer-connected digestion mixture.

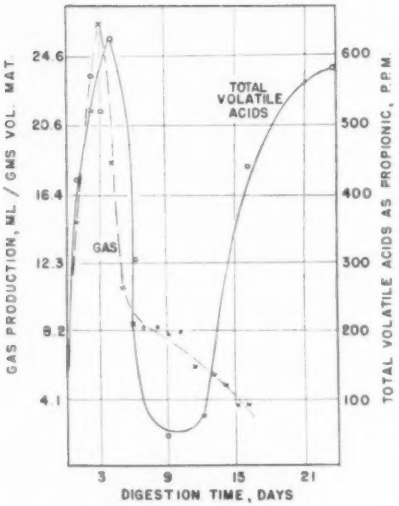


**FIGURE 4.—Total volatile acid concentration and daily gas production from digestion of paperboard mill white water.**

*White Water*

Experimental results obtained with the white-water digestion are presented graphically in Figures 4 and 5.

Figure 4 is a plot of daily gas production and of the total volatile acids accumulation (as propionic) in the digestion mixture. The rate of gas production increased rapidly and reached a peak on the third day, then dropped sharply during the fourth and fifth days. From the sixth day on, the rate of gas production decreased gradually until the 16th day, when gas production was considered complete. The average gas yield was 160 ml. per gram of volatile matter.

Gas composition showed a quick rise in carbon dioxide percentage during the first four days of digestion, followed by a gradual reduction. The maximum carbon dioxide percentage reached was 19.1, which is appreciably lower than normally obtained in sewage sludge digestion.

Figure 5 presents individual acid accumulation during the digestion. Only acetic and butyric acids were found. Both the acetic and butyric acids occurred in the form of two distinct acid peaks, which were more marked with the former. An apparent disappearance of both acids occurred between the 8th and 12th day of digestion, followed by a sharp increase of acetic and a gradual increase of butyric acid.

*Slaughterhouse Waste*

A composite table of average results obtained per day from the digestion of slaughterhouse waste loaded on a daily basis are presented in Table I. Detailed results (3) indicated that a rather constant level had been reached during the 6½ days of digestion, as repeatedly shown by the determinations of B.O.D. reduction, carbon dioxide in the gas, gas per gram of

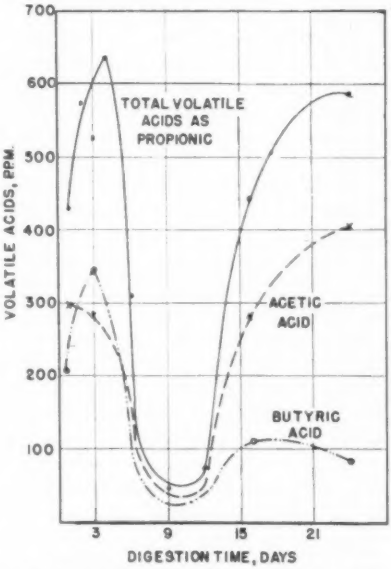


**FIGURE 5.—Total and individual volatile acid concentrations during digestion of paperboard mill white water.**

volatile matter added, pH, volatile solids reduction, and volatile acids in the supernatant.

The loadings increased from 0.098 lb. to 0.157 lb. B.O.D.[1] per cubic foot per day, with decreasing digestion time from 1 day to 0.625 day, respectively. The digestion receiving the higher loadings was further "taxed" by its decreased detention time, so that the sharp differences in B.O.D. reduction, volatile solids reduction, volatile acids accumulation, and gas production with the various digesters became apparent.

**TABLE I.—Digestion of Slaughterhouse Waste Loaded on a Daily Basis**

| Item | Average Results, Per Day | | |
|---|---|---|---|
| (1) Loadings (lb. B.O.D./cu. ft.) | 0.098 | 0.130 | 0.157 |
| (2) pH | 6.86 | 6.63 | 6.44 |
| (3) B.O.D. added (lb.) | 0.00346 | 0.00692 | 0.01384 |
| (4) Vol. solids added (lb.) | 0.00398 | 0.00796 | 0.01592 |
| (5) Detention time (days) | 1.0 | 0.75 | 0.625 |
| (6) Gas per g. vol. matter added (ml.) | 337 | 165 | 53.4 |
| (7) Gas per g. vol. matter destroyed (ml.) | 440 | 220 | 110.8 |
| (8) $CO_2$ in gas (%) | 7.42 | 6.58 | 4.04 |
| (9) B.O.D. reduction (%) | 79.5 | 44.3 | 17.6 |
| (10) Vol. solids reduction (%) | 81.5 | 75.0 | 51.0 |
| (11) Susp. sol. in sup. liq. (p.p.m.) | 34.4 | 63.8 | 84.8 |
| (12) Vol. acids in sup. liq. (p.p.m.)[3] | 50.4 | 313 | 552 |
| (13) Total vol. acids in gas and sup. liq. (mg./g.[2]) | 408 | 277 | 136 |
| (14) Total vol. acids in gas and sup. liq. (mg./g.[4]) | 498 | 368 | 242 |
| (15) Ash in sludge, initially (%) | 24.9 | 31.2 | 28.8 |
| (16) Ash in sludge, finally (%) | 59.2 | 59.2 | 59.2 |

[1] As propionic.
[2] Volatile matter added.
[3] Volatile matter destroyed.

In Figure 6 are presented the total volatile acids (as propionic milligrams per gram volatile matter destroyed) in the effluents from the digesters. The volatile acid contents of the effluents were markedly uniform, varying at most 50 to 75 p.p.m. Of all the analyses, the volatile acid determinations were least affected from day to day. With constant daily loads the volatile acid level should not fluctuate, and with higher loads higher volatile acid levels should correspondingly be attained. The results show that such was the case. The individual volatile acid

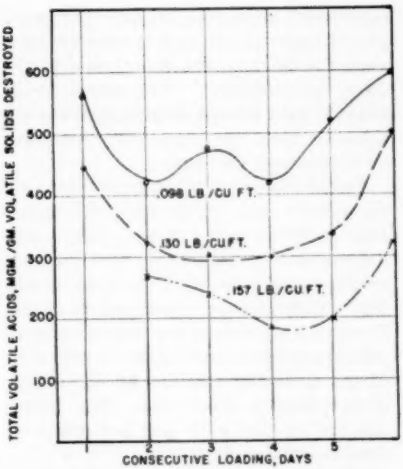


**FIGURE 6.—Total volatile acid production, including gas converted to equivalent amounts of volatile acid, during digestion of slaughterhouse waste mixtures of different daily raw waste loadings.**

determinations presented in Table II substantiate the above statements. With lower loadings, two-day composite samples (see Table II) were necessary to obtain sufficient acid concentration for analysis by the countercurrent technique.

A comparison of the fourth and sixth day volatile acid composition obtained with the waste mixture loaded at 0.157 lb. B.O.D. per cubic foot indicates the similarity of these two samples.

The individual acids present were identical, and the concentrations of

**TABLE II.—Individual Acid Analysis of Supernatant Liquor from Digestion of Slaughterhouse Waste Mixtures**

| | 3rd 2-Day Composite | 4th Day | 6th Day |
|---|---|---|---|
| Loadings, B.O.D. (lb./cu. ft.) | 0.130 | 0.157 | 0.157 |
| Acetic acid (p.p.m.) | 54 | 231 | 260 |
| Propionic acid (p.p.m.) | 81 | 88 | 88 |
| Butyric acid (p.p.m.) | 124 | 145 | 104 |
| Valeric acid (p.p.m.) | 141 | 104 | 96 |
| Total vol. acids (p.p.m.) | 400 | 568 | 548 |

each were almost identical. The propionic and valeric acid concentrations were the same on the fourth and sixth days, respectively. The acetic and butyric acid concentrations differed so little on these two days that they can be considered the same.

In the lower loaded mixture of 0.130 lb. B.O.D. per cubic foot, the same four acids were also found. The only difference was the much lower acetic acid accumulation with the lower loading. This may be attributed to more favorable conditions for digestion and, consequently, more rapid conversion of the acetic acid to gas by the methane-producing organisms. The lower loading yielded more gas per gram of volatile matter destroyed.

## Discussion

Application of volatile acid studies to several digesting industrial wastes has produced some interesting results. Batch digestion studies of the yeast waste rich in nutrient resulted in volatile acid accumulations which were similar in some respects to fresh solids digestion (4), but differed in others. Total volatile acid production was similar to digesting fresh solids (4), in that properly loaded yeast waste mixture showed a sharp drop in the accumulated acids to a low constant level, coinciding with increased gas production. The overloaded yeast waste mixtures accumulated volatile acids rapidly, coinciding with negligible gas production. The high acid level remained until more favorable digestion conditions were restored, with subsequent rapid disappearance of the acids. Again, the similarity to fresh solids digestions (4) consisting of unseeded, limed, or improperly digesting seeded solids is apparent.

Individual acid accumulation is different in overloaded yeast waste mixtures from that in fresh solids digestions. Four lower volatile fatty acids (acetic, butyric, propionic, and valeric) were found in measurable amounts, whereas fresh solids digestions indicated only three acids (acetic, propionic, and butyric). Acetic and butyric acid accumulations were similar in both series of yeast digestions; they rose rapidly to a peak and then decreased rapidly as digestion became favorable. The occurrence of both propionic and valeric acids was similar in each. These acids did not appear in sufficient concentration until the peak of acid accumulation had passed, then rose quickly to a maximum, followed by a gradual disappearance.

It appears logical that the lower molecular weight substances, such as acetic, would be utilized by the organisms first, for food, before the organisms attack the more complex substances, such as the high molecular weight proteins. A state of vigorous degradation may be needed to produce hydrolysis of the more complex materials. This may explain the second propionic acid peak obtained with slowly digesting treated and untreated fresh solids (4). The first peak may have been due to the breakdown of available compounds, such as lactic acid.

The digestion of white water low in food materials differed from either the fresh solids (4) or yeast waste digestions. Only two acids, acetic and butyric, were found during the entire digestion. Probably a digestion mixture consisting primarily of carbonaceous material and lacking the nutrients present in the more complex substrates yields only the simpler volatile acids, such as acetic and butyric.

The study of volatile acid production during the digestion of slaughterhouse waste differed from the other industrial waste experiments in that the digesters were fed on a daily basis. Although various daily loadings were applied and different detention times employed, the daily analyses indicated uniform digestion in each of the mix-

tures. Analyses showed that the volatile acids accumulate to a definite concentration and remain at this level if the loadings are kept constant. The individual acid analyses (Table II) showed identical acids present (acetic, propionic, butyric, and valeric) on the different days and almost identical individual acid concentrations, substantiating the uniformity of digestion. Hence, at constant loadings, a constant total volatile acid accumulation level in the digestion mixture on successive days appears to be a good indication of uniformity of operation.

## Summary

A series of experiments was conducted on several industrial wastes by batch and continuous feeding processes. Various analyses were made of the waste material during digestion, and special emphasis was placed on the total and individual lower volatile acids produced.

## Conclusions

1. The Craig countercurrent technique can be adapted satisfactorily for the analysis of volatile acids present in industrial wastes.

2. Acetic, propionic, butyric, and valeric acids were found present during the decomposition of overloaded yeast waste mixtures.

3. During overloaded yeast waste digestions propionic and valeric acids increased rapidly after the maximum total acid accumulation had been reached.

4. Digestion of white water showed the accumulation of only acetic and butyric acids.

5. The individual volatile acids found in digesting slaughterhouse waste were acetic, propionic, butyric, and valeric.

6. Total volatile acid determinations may be used to indicate the efficiency of continuously fed slaughterhouse digestions.

## Acknowledgment

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# RECOVERY OF CHROMIC ACID FROM PLATING OPERATIONS *

By F. R. Keller, C. C. Cupps, and R. E. Shaw

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Many authors have pointed out that the design of an industrial waste disposal plant starts with a reappraisal of operating layout and processes.

The present paper describes a case in point. At the Standard Steel Spring Company's Newton Falls, Ohio, plant, installation of a recovery system has already resulted in a reduction of 55 per cent in the amount of chromic acid lost by drag-out. Not only has this materially reduced the load on the treatment plant and saved some $1,650 monthly on ferrous sulfate used for treatment, but it also has paid off in reduced chromic acid consumption at the rate of $2,500 monthly. The recovery system cost approximately $10,000 to install and operation costs are about $500 per month. Even though the recovery plant has not been operating consistently at its designed efficiency, it had paid for itself three months after installation.

Not every chromium plating operation would yield such spectacular savings from a similar installation, but wherever drag-out represents a substantial proportion of chromic acid usage, the situation will be very similar. It is suggested that many operators will be surprised if they calculate the chromic acid corresponding to the chromium deposited in a month and compare this figure with actual chromic acid usage.

At Newton Falls, where automobile bumpers are plated automatically, the drag-out is quite heavy, owing to the cup formed at the bottom when a bumper is hung vertically. Each bumper carries with it from ¼ to 1 pint of solution, which represents a considerable fraction of the daily usage of chromic acid. The following percentages represent the use of chromic acid with a double recovery tank before any further recovery system was installed:

| | |
|---|---|
| Chromic acid used to deposit chromium | 5.7% |
| Misc. losses, incl. fume exhaust (est.) | 20.0% |
| Drag-out | 74.3% |
| Total | 100.0% |

The successful use of a recovery tank depends upon an appreciable quantity of the drag-out liquor being used in the plating or process tank. Normally, the only use for drag-out liquors in a plating tank is to replace loss of solution by evaporation, since the drag-in is equivalent to the drag-out on the work being processed. Decorative chromium plating tanks, however, are usually operated at 110° to 125° F., which results in very little evaporation.

## Process Modification

To improve the operation of the recovery tanks at Newton Falls, the amount of solution continuously taken from these tanks was materially increased, first, by reducing the drag-in to the plating tank and, second, by installing an evaporatory to reduce the volume of drag-out solution before adding it to the plating tank.

The flow sheet (Figure 1) of the installation shows the two rinses (tanks

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; St. Paul, Minn.; Oct. 8–11, 1951.

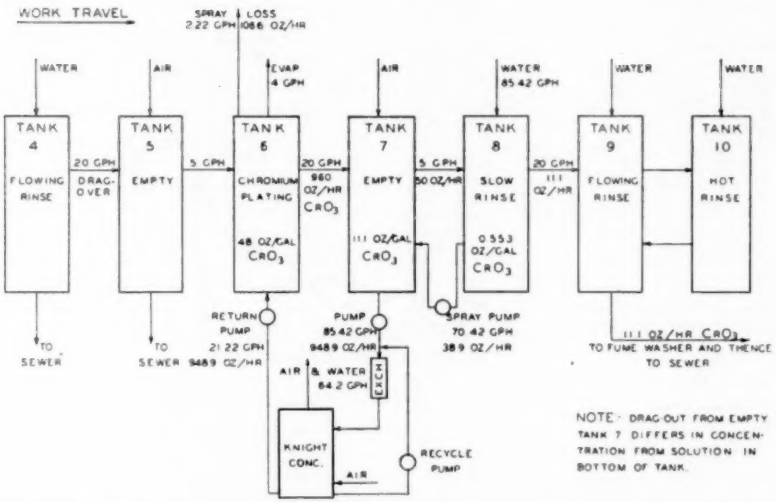


**FIGURE 1.—Flow diagram of part of plating cycle as altered to recover chromic acid, showing designed flow rates and equilibrium concentration of $CrO_3$.**

4 and 5) preceding the plating tank and the three cold rinses (tanks 7, 8, and 9) and final hot rinse (tank 10) following it. This normal rinsing cycle has been altered as follows:

1. Tank 4 is operated normally; that is, full and overflowing to sewer.

2. Tank 5 is operated empty. Blow-off fixtures (Figure 2) remove the bulk of the water carried in the bumpers by a blast of air.

3. Tank 7 is also operated empty. The bumpers are first rinsed by a spray, which is mechanically arranged to operate intermittently; that is, when the carrier is in proper position. The diluted drag-out now carried by the bars is then blown off by air jets as in Tank 5.

4. Tank 8 is operated full, but not overflowing. The sprays for tank 7 are fed from tank 8 by means of a small centrifugal pump, and only enough fresh water is added to tank 8 to replenish this spray water and the normal drag-out. Thus, the only portion of the chromic acid drag-out which finds its way to waste is that dragged out of tank 8. Therefore, the primary object is to keep the concentration in this tank to a minimum.

Referring again to Figure 1, it will be seen that the efflux from tank 7, containing the bulk of the chromic acid drag-out, is pumped through a flow meter and heat exchanger to the concentrator. A portion of the concentrate is recycled, the rest being returned to the plating tank substantially at plating bath concentration. It will also be seen that the chief work by the concentrator is to evaporate the water used by the sprays in tank 7, providing that both blowoffs are equally efficient, so that the drag-in from tank 5 equals the drag-out from tank 7. Also, after this water is evaporated, the solution has once again the approximate composition of the plating bath. This means that there is always room for it in the plating tank.

It may be observed that it would be very desirable to blowoff the bulk of the concentrated solution over the

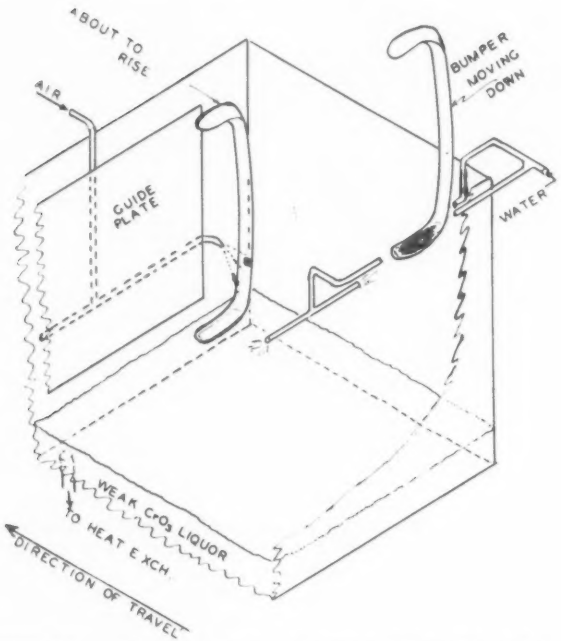


**FIGURE 2.—Schematic diagram of spray and blowoff in tank 7, where major part of chromic acid is recovered.**

plating tank itself, but for mechanical reasons that was not practical.

### Design of Evaporator

The design of the evaporator system presents a major problem, owing to the corrosive nature of hot chromic acid. In the past, attempts have been made to concentrate chromic acid drag-out in open steel or lead tanks, using lead steam coils. Invariably these have wound up on the scrap heap, because of corrosion. Without some method of providing enough room in the plating tank for the return, it was often necessary to concentrate to a sirupy liquor, which was difficult to handle and very corrosive when hot, even to lead. These operations were usually performed batchwise, and because even dilute chromic acid at boiling temperatures attacks lead, especially at the air-liquid junction, this attack occurred all down the side-walls as the liquid level fell during evaporation. In addition, the lead coils became heavily encrusted, which interfered with the heat transfer.

In the present design, a Knight concentrator (Figure 3) is used. In this unit air is introduced below a bed of berl saddles, while the hot (but not boiling) liquor is trickled down from the top. The air picks up moisture and carries it out at the top, passing first through another thin layer of smaller saddles to remove entrained chromic acid.

At first it was thought that it would be satisfactory to operate the heat exchanger with steel tubes, which would be expendable but cheap. The loss of tubes and consequent shut-down, however, proved excessive, and a pyrex

heat exchanger is now being used. Low-temperature pipelines are of iron; all pumps are of Duriron. One interesting feature is the use of Teflon envelopes surrounding the gasketing materials at the flanged joints of the pyrex assembly. A Teflon envelope shaped like a flattened inner tube, but open on the outside diameter, is used. This permits the insertion of a split gasket of any convenient material, which is then effectively insulated from the action of the solution.

It has already been observed that the function of the concentrator is to evaporate the water added to tank 8 and used for the sprays in tank 7. Because the ultimate loss of chromic acid is controlled by the equilibrium concentration in tank 8, it is essential to keep this concentration at a minimum. This is done by making the flow of fresh water and spray equal to the evaporation capacity of the concentrator. One can calculate what savings in chromic acid are possible for a given size of evaporator, and thus choose the most economical size for the job. Due allowance must be made for the savings in disposal plant installation and operating costs.

**TABLE I.—Design Data for Chromic Acid Recovery System**

| Factor | Transfer or Drag-out (gal./hr.) | $CrO_3$ Conc. (oz./gal.) | $CrO_3$ Drag-out or Transfer (lb./hr.) |
|---|---|---|---|
| Drag-out from plating tank 6 | 20 | 48 | 60 |
| Drag-out from rinse tank 8; loss | 20 | 6.1 | 0.8 |
| Water feed to rinse tank 8 | 85.4 | 0 | 0 |
| Draw-off from empty tank 7 | 85.4 | 11.1 | 59.2 |
| Vapor from concentrator | 64.2 | 0 | 0 |
| Return to plating tank 6 | 21.2 | 44.6 | 59.2 |

Without going into too much detail, the recovery system was designed on the basis shown in Table I and Figure 1.

Based upon the data in Table I, the drag-out from the plating tank (60 lb. of chromic acid per hour) would be a total loss if no recovery of any kind were used. By actual measurement at various times, it was determined that the double rinse recovery tanks were saving one-half of this drag-out, corresponding to 30 lb. of chromic acid per

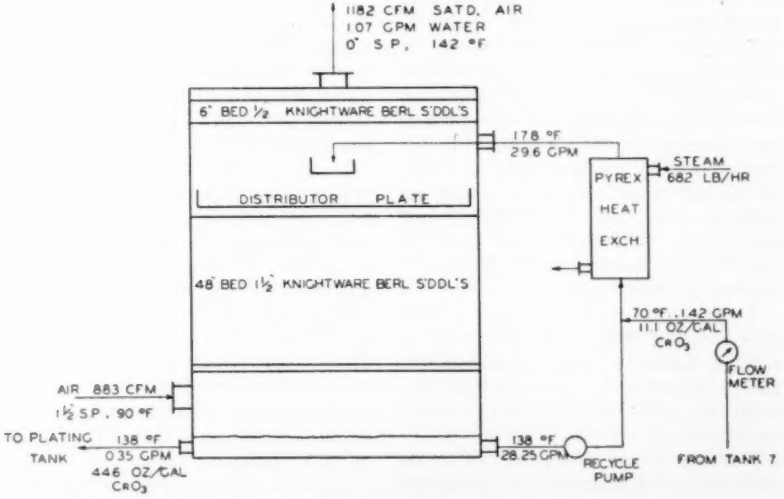


**FIGURE 3.—Diagram of Knight concentrator for chromic acid recovery.**

hour. Use of the evaporator and the combination spray and blowoff arrangement has reduced this loss again by more than 50 per cent, corresponding to a saving of at least 45 lb. of chromic acid per hour. Recent checks have shown that the loss may be as low as 3 lb. of chromic acid per hour using the latter method of operation.

Other means of recovering the drag-out have been proposed, such as vacuum evaporators and ion exchangers. All of these systems, including the one described here, have the advantage that the waste disposal problem is handled right at its source by reducing the waste concentration before the waste is treated.

### Acknowledgment

The authors wish to thank A. Kenneth Graham, of Graham, Crowley, and Associates, Inc., for his many suggestions and his help in this undertaking.

## DISCUSSION

By Don E. Bloodgood

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The authors have outlined an industrial waste problem and have described in detail how it was solved. So many industrial waste problems seem to be monstrous until a thorough analysis of all factors has been made. In many instances the so-called industrial wastes are not materials left over from the manufacture of a particular item, such as the vines in the production of canned peas, but they are a usable product, such as the paint lost in spray painting.

There is absolutely no reason to doubt the statements made by the authors regarding the savings resulting from their described recovery processes. It is not often that industries will report extensive losses prior to their giving attention to them, probably because the engineers and executives cannot believe that they could possibly have been so wasteful and still have remained in business.

There seems to be no basic reason why the evaporation or concentration method cannot be operated successfully and it should not be frowned upon because of a few difficulties with control apparatus.

Perhaps a somewhat less effective method of elimination of drag-out might in some instances suffice; if it will, it might be possible to encourage the development of a vibrator that will shake off most of the plating solution prior to rinsing. Attempts have been made to get plating machine manufacturers to develop such a vibrator. The effectiveness of such equipment has been and can easily be demonstrated by having someone lightly tap the plating rack with a wooden mallet.

There have been some who objected to the use of air blasts in removing plating solutions containing cyanide for fear that enough cyanide might be blown into the air to cause poisonings. Hoods and vents can be devised to overcome such dangers.

It would seem that the corrosion problem mentioned by the authors might be partially overcome by building the evaporator equipment in such a way that the heating units and tank linings were the materials to receive plating deposits instead of being corroded away—in other words, bring about electrolytic protection of the evaporating equipment.

The straightforward reporting of the authors states again that the reduction in manufacturing losses is very effective in the solution of industrial waste problems.

# THE PLATING WASTES PROBLEM FROM THE ELECTROPLATER'S VIEWPOINT *

By A. K. Graham and H. L. Pinkerton

*President † and Chemical Engineer, respectively, Graham, Crowley and Associates, Inc., Jenkintown, Pa.*

Increasing emphasis on stream pollution abatement and the treatment of electroplating wastes in recent years has focused attention on the very complex nature of the problem, and the purpose of this paper is to discuss several aspects of the problem from the electroplater's viewpoint. An attempt is made to define the electroplating industry and the nature of the plating waste. A distinction is made between plants discharging waste into public waters and into municipal sewers, and the problems related thereto are briefly discussed. Finally, the interdependence of the sanitary engineer (or architect) and the electroplating engineer for successful handling of plating waste problems is emphasized. An additional object of this paper is to effect a better understanding of the plating waste problem mutually among the several groups concerned—the plating industry, the sewage treatment group, and those responsible for maintaining the purity of public waters.

## The Plating Industry and Plating Waste

The electroplating industry may be considered to cover broadly all kinds of metal finishing. This would include electroplating, electroforming, chemical coloring, surface treatment with phosphates or chromates, anodizing, painting, and lacquering. The base metals involved may be copper; ferrous alloys, including stainless steels; and alloys of copper, zinc, aluminum, magnesium, and lead. Non-metallic base materials (such as plaster of Paris, plastics, etc.) may also be electroplated. Acids and alkalies, both concentrated and diluted, are used in the preparation of the base surfaces for the various finishes. The plating baths may be acid or alkaline and are almost without exception water solutions of salts of the metals to be deposited. Therefore, the waste from a plating establishment may include any combination of the metals and anions shown in Table I.

It is probably safe to say that the waste from any one plant would never contain all of the constituents listed in Table I and, ordinarily, ingredients contributing to B.O.D. are low. However, plating wastes may vary greatly, as compared to most plant wastes, since any combination of these constituents may be present and in widely different amounts. Because of this, an analysis of the proper handling and treatment of each plant's waste on an individual basis is essential. Also, the cost of the installation and its operation may vary widely.

The electroplating industry may also be classified as to the type of establishment; namely, (1) job or contract plating shops, and (2) concerns manufacturing a great variety of end products, from automobiles to costume jewelry, which do most of their own metal finishing. The essential difference is that job shops are primarily concerned with

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† Also Executive Secretary, American Electroplaters' Society, Inc.

**TABLE I.—Possible Constituents in Electroplating Waste[1]**

| Metals | Anions |
|---|---|
| Ammonium | |
| Sodium | OH |
| Potassium | $SO_4$ |
| Calcium | $PO_4$ (or complex) |
| Magnesium | $NO_3$ |
| Aluminum | $NO_2$ |
| Zinc | Cl |
| Cadmium | |
| Nickel | F |
| Cobalt | S |
| Iron | $BF_4$ |
| Chromium | $CrO_4$ |
| Lead | CN (free or complex) |
| Tin | CNO |
| Copper | $CO_3$ |
| Silver[2] | $SiO_3$ (or $SiO_4$) |
| Gold[2] | $R_xCOO^3$ |
| Indium[2] | $R_xSO_3$ |
| Platinum group[2] | $SO_3$ (or equiv. source of $SO_2$) |

[1] Paint waste, solvents, and lubricants may also be present.

[2] These high-cost metals are usually removed by recovery methods.

[3] Such as formates, acetates, citrates, and tartrates, as well as higher fatty acid salts.

metal finishing but not manufacturing, whereas the other concerns manufacture products, the finishing of which is a very important requirement. The latter type concerns represent about 80 to 90 per cent of the electroplating industry in terms of the capacity of facilities installed or the quantity of metals and chemical consumed.

## The Waste Problems

It should be pointed out that the chemical nature of the plating waste and the kind of problems which its disposal presents are not usually different for either type of electroplating establishment. Actually, the kind of finishing operations employed in a plant will determine the chemical nature of the waste. This will also have a direct bearing on some of the problems involved in the treatment of the waste. However, the most difficult problems may arise because of the specific location of the plant. This phase of the subject is discussed later.

The plating industry generally recognizes that the treatment of various kinds of plating wastes—such as pickle liquor, cyanides, chromic acid or chromates, organic matter of various kinds, and other plating wastes, comprising salts of the heavy metals used in plating—naturally differ. The industry is also seeking needed information on treatment methods, analytical controls, and standards, as indicated by the following activities:

1. Waste treatment studies under the research program of the American Electroplaters' Society.
2. Related studies on the establishment of standards for waste treatment conducted by the Metal Finishing Industry Actions Committee of the Ohio River Valley Water Sanitation Commission.
3. Company-sponsored investigations, as reported from time to time in the technical literature and in private communications.

The trend in much of the latter activity is toward the reduction or complete elimination of certain wastes through engineering improvements in the recovery of spray paint residues and drag-out from plating and finishing operations, and in more efficient use of rinse waters. This is one of the most promising approaches to the solution of the whole plating waste problem, as economies affected in the recovery of chemicals and in the reduction of waste to be treated both hasten and encourage compliance on the part of the industry. To further emphasize the possibility of these economies, one need only point out that, on the basis of the cost of chemicals alone,

1. A pound of sodium cyanide in a waste costs 18¢, and the chlorine required for its complete destruction costs 80¢.
2. A pound of chromic acid in a waste costs 28¢, and the ferrous sul-

fate and sulfuric acid required for its complete reduction may cost 23.5¢, including handling charges.

### Plant Location

The influence of a plant's location on the problems encountered in the treatment of waste is not as clearly understood as the technical aspects previously discussed. It is also much more difficult to evaluate. In the case of plants discharging waste directly into public waters, rather than through sanitary sewers, the requirements for treatment not only vary from state to state, but also at different locations within a state. Because of this and the fact that conditions vary from one plant to another, the specific waste problem of each plant must be dealt with individually by the state's engineers. Fortunately, these officials have generally assumed a realistic attitude in these dealings. Otherwise, the industry would be faced with much greater hardships.

Plating plants located in urban areas and obliged to discharge waste into sanitary sewers may be faced with even more serious problems. In the first place, the local municipality is responsible for its own sewer ordinances, which distribute the responsibility more widely than when dealing with state authorities. As pointed out in the Federation's "Manual of Practice No. 3" (1949), "the specifications of what may and what may not be discharged to the various types of public sewer systems is a major responsibility of the sewer ordinance. Practice in prevailing codes with respect to this item is again highly variable." Adjustment of the pH of the waste to avoid corrosion of the sewer system and interference with the biological reactions is generally required, but there is not too much agreement as to the pH value. Some municipalities will accept plating waste with appreciable quantities of B.O.D., suspended solids, or cyanides and copper, whereas others set limits or require substantially complete elimination of certain constituents before discharging the waste into the sewer.

Under what conditions can these constituents be discharged into sewer systems without adverse effects upon the sewage treatment processes and what limited amounts can be safely handled? It is of vital importance to the electroplating industry that these matters be clarified. The plant discharging into a municipal sewer is always located in an area in which ground or floor space is relatively scarce and costly. Therefore, to carry out any waste treatment creates an unusual economic problem and in some instances an impossible space problem.

### Cooperation of Engineering Talent

There is one other phase of the plating waste problem that should be discussed; namely, how can a plating concern best proceed in solving its own waste disposal problems? There is a tendency to believe that this is a job for the sanitary engineer, although in some instances the responsibility may be assigned to an architect. However, Price recently stated, in a paper presented at the annual convention of the American Electroplaters' Society, "With few exceptions, consulting engineers will not have a background in electroplating and are likely to be unfamiliar with the special problems of this industry." This point needs special emphasis because of the complexity of the problem and because a treatment plant for plating waste must perform successfully by meeting the standards prescribed for the plant effluent. It must also satisfy any anticipated increase in load or process changes and still operate at the lowest possible cost. To accomplish this, the services of a competent electroplating engineer will be needed because the design data upon which the treatment plant is to be en-

gineered should be supplied by him. Fortunately, many of the larger manufacturing concerns have able electroplating engineers in their employ, and competent consultants are also available.

### Summary

1. The chemical nature of a plating waste is determined by the kind of plating or finishing operations employed in a plating establishment and not by the type establishment as defined.

2. The technical problems involved in the treatment of plating waste are generally understood and are being further investigated by the industry.

3. The problems in waste treatment related to a plant's location involving the discharge of waste into public waters or municipal sewer systems are varied, difficult to define, and require realistic cooperation on the part of state and municipal officials to avoid undue hardships in the industry.

4. There is a need for information on the effect of plating waste ingredients on sewage treatment processes as an aid to the industry in order to determine what ingredients may be tolerated, in what concentrations, and under what conditions.

5. Services of a competent electroplating engineer, in addition to those of a sanitary engineer, are required for satisfactory handling of electroplating waste problems.

## DISCUSSION

By William S. Wise

*Chief Engineer, State Water Commission, Hartford, Conn.*

The authors have presented certain phases of the plating wastes problem that deserve more emphasis and stimulate comments from somewhat different viewpoints. They have stated that one of the objects of the paper is to effect a better understanding among the different groups of interests concerned. This is most commendable, because those who, for years, have butted their heads against the stone wall of pollution abatement have realized that one of the main barriers to the solution of many of these problems was the lack of interest and the lack of understanding and cooperation between the industrialist, the local citizens and municipal officials, and the pollution abatement agency. Some of the difficulties may have been due to the fact that the problems were viewed through different ends of a telescope. It would be helpful if everyone looked through the same end of the telescope, even though the focus has to be adjusted to fit individual viewpoints.

This is all the more important for an industry producing wastes with such a variety of ingredients, degrees of toxicity, and, sometimes, such damaging effects upon the receiving waters. The program of the American Electroplaters' Society, including research in the production, handling, treatment, and disposal of these types of wastes, is a credit to the industry and should be generously supported so that at an early date corrective measures can be applied to the many plants creating serious conditions in receiving streams and sewage systems. A great advantage of A.E.S. is that its members look to it for guidance and help.

The authors quite appropriately point out some of the difficulties due to plant location, whether directly on a river or on a sewage system. It is probably a fact that if the industrialists had been sufficiently cognizant of the need for and the importance of adequate waste disposal facilities when locating their manufacturing plants,

many of these problems today would not exist or would be considerably simplified. Even today, with the great national emphasis on the importance and need for adequate waste treatment, this problem is either overlooked or given only a casual consideration in the selection of new industrial sites. It is only natural for an industry to expect sewage facilities for disposal of its industrial wastes when its taxes are helping to build, operate, and maintain these great assets of sanitation; but their acceptance would not be fair if, because of the volume or character of its wastes, increased costs of operating the system place an unjust burden upon all the other users. It is more than safe to assume that the average industrialist, when informed of the possible difficulties, would not expect to utilize such facilities to the detriment of the municipality.

It is almost startling to realize how low the concentrations of certain substances may be to adversely affect sewage treatment processes. For example, if 2 p.p.m. each of copper, zinc, and nickel were discharged constantly to a sewage treatment plant and if it is assumed that 50 per cent of these metals (1 p.p.m.) were precipitated in the sludge, then the concentration of each would be about 400 p.p.m. There is not complete agreement on the toxic effect of these metals upon sludge digestion processes. However, it is generally conceded that up to 100 p.p.m. copper has a beneficial effect upon digestion, but above 200 p.p.m. the toxic effect becomes increasingly detrimental. The combined effect of these three metals alone might be most damaging.

Furthermore, if low concentrations of chromium reached a sewage treatment plant employing secondary treatment (either trickling filters, sand filters, or activated sludge), this metal in its chromic and most toxic form would not be precipitated in the sludge, but would pass through the settling tanks into the secondary processes and there inhibit nitrification and the biological processes. In some instances, the treatment of industrial wastes necessary for discharge directly to a waterway would be less stringent, or at least no more stringent, than that required for discharge to a sewer system. Therefore, in such cases why burden the sewer system with the additional volumes of water? Serious thought should be given to the discharge of detrimental industrial wastes or industrial wastes in general to sewer systems where secondary sewage treatment processes may become necessary at some future time, because it is possible that such discharges might prevent the use of higher degrees of sewage treatment, especially if biological processes are included. Character and volumes of industrial wastes may change quickly and radically.

The authors emphasize the need of all parties to assume an informative and realistic approach to avoid undue hardships in the industry. In this, all can concur. However, it is also necessary to realize that the industry is a part of the community in which it is located and one is mutually dependent upon the other so that an injury to one is reflected in some degree upon the other. This fact underlines the authors' suggested place of the electroplating engineer, because pollution abatement work starts in the plating room and a close cooperation between the electroplating engineer and the sanitary engineer is bound to result in the most satisfactory and economical solution.

# DETERMINATION OF TOTAL AND REDUCING SUGARS IN CITRUS WASTES *

By W. N. Wells, P. W. Rohrbaugh, and Glen A. Doty

*Respectively, Engineer's Assistant, Citrus-Canning Waste Research Project; Director, Citrus and Vegetable Training Center, Texas College of Arts and Industries; and Project Supervisor, Citrus-Canning Waste Research Project, Weslaco, Tex.*

The Benedict method (1) for the determination of reducing sugars has been used extensively by the writers, but has never been entirely satisfactory, due to the difficulty of obtaining reproducible results.

The Blish method (2) for the determination of reducing sugars, developed for study of the diastatic value of flour, was adapted for the determination of sugars in orange juice and orange peel by Rohrbaugh (3). Briefly, the method consists of the alkaline oxidation of reducing sugars by a potassium ferricyanide solution. After oxidation for 20 min. at the boiling temperature of water, the mixture is cooled rapidly and the excess potassium ferricyanide determined by iodimetric methods. Pritchett and Stevens (4) further studied the method as applied to citrus products and concluded:

1. The excess ferricyanide may vary over wide limits without materially affecting the accuracy of the results; 10 ml. of ferricyanide solution are used in the test and the excess may vary from 0.13 to 7.15 ml.

2. The oxidation period may vary from 18 to 22 min. without seriously affecting the results.

3. The solution to be tested should be near neutral or slightly basic.

4. The operator is not a critical factor, as is the case with the Benedict method.

The present study was undertaken to test the applicability of the method to the determination of small quantities of sugars in citrus canning wastes in the presence of domestic sewage. Tests made indicate that the method is excellent for this purpose. It was found that the reducing sugar content of raw sewage varied from about 0.004 to about 0.01 per cent and that total sugar varied from about 0.02 to about 0.03 per cent. Whether these values actually represent sugars in sewage or some other easily oxidizable material was not determined. Sewage samples with known quantities of sugars added were analyzed; the sugar found checked closely with the amount of sugar added.

## Experimental Results

Five samples of raw sewage were obtained from five different towns. The samples were filtered and tested for reducing and total sugars. The tests for reducing sugars were run on undiluted samples. The samples for

**TABLE I.—Sugar Analyses of Raw Sewages**

| Sample No. | Reducing Sugars, as Dextrose (%) | Total Sugars, as Dextrose (%) |
|---|---|---|
| 1 | 0.00453 | 0.0166 |
| 2 | 0.00604 | 0.0211 |
| 3 | 0.00846 | 0.0151 |
| 4 | 0.00634 | 0.0242 |
| 5 | 0.01058 | 0.0302 |

* This investigation was carried on as a portion of the Citrus-Canning Waste Research Project at Weslaco, Tex., made possible by a grant to the Texas State Department of Health by the United States Public Health Service under the provisions of Public Law 845.

TABLE II.—Recovery of Added Sugar from Sewage Samples

| Sample No. | Dextrose Added (%) | Dextrose Found (%) | Sucrose Added (%) | Total Sugar Found, as Dextrose (%) |
|---|---|---|---|---|
| 1 | 0.10 | 0.103 | 0.10 | 0.115 |
| 2 | 0.20 | 0.204 | 0.20 | 0.205 |
| 3 | 0.40 | 0.408 | 0.40 | 0.400 |
| 4 | 0.80 | 0.800 | 0.80 | 0.814 |
| 5 | 1.60 | 1.540 | 1.60 | 1.592 |

total sugars had a final dilution of 1:10 after inversion. Table I shows the results of these analyses.

Various percentages of dextrose and sucrose were added to the samples of filtered sewage. The samples were then analyzed for reducing and total sugars. The results of these analyses are shown in Table II.

Table III shows the results of tests of miscellaneous citrus products and wastes.

## Method for Determining Total Sugars

*1. Reagents*

1.1. Acetic acid mixture. Dissolve 70 g. of KCl and 20 g. of $ZnSO_4 \cdot 7H_2O$ in about 500 ml. of distilled water. Add 200 ml. of glacial acetic acid and make up to 1 l. with distilled water.

1.2. Potassium iodide. Dissolve 500 g. of KI in distilled water and make up to 1 l. Add a few drops of NaOH solution to prevent the formation of free iodine.

1.3. Starch solution. Triturate 5 g. of starch into a paste with a little water, and add slowly to 1 l. of boiling water. Boil for 1 or 2 min., cool, and add about 0.2 g. of salicylic acid. Allow to settle overnight and decant the clear solution.

TABLE III.—Sugar in Citrus Products and Wastes

| Sample | Reducing Sugar, as Dextrose (%) | Total Sugar, as Dextrose (%) |
|---|---|---|
| Canned grapefruit juice | — | 8.39 |
| Canned orange juice | — | 9.89 |
| Citrus molasses | 26.50 | 34.20 |
| Peel bin drippings | 6.02 | 8.30 |

1.4. Sodium thiosulfate, 0.025 N. Dilute 250 ml. of 0.1 N sodium thiosulfate to 1 l. with distilled water. The 0.1 N thiosulfate is standardized by the method given in Theroux, Eldridge, and Mallmann (5), as follows:

Dissolve 24.820 g. of sodium thiosulfate in distilled water and make up to 1 l. Add 0.2 per cent of sodium hydroxide as a preservative. Standardize against 0.1 N potassium biniodate ($KIO_3$–$HIO_3$), which is prepared by dissolving 3.250 g. of the dry salt and making up to 1 l. Dissolve about 5 g. of KI crystals in about 100 ml. of distilled water. Add 10 ml. of 1:10 $H_2SO_4$ and exactly 25 ml. of the biniodate solution. Titrate the liberated iodine with thiosulfate and adjust the normality of the thiosulfate until it is exactly 0.1 N.

1.5. Potassium ferricyanide, 0.05 N. Dissolve 16.50 g. of dry $K_3Fe(CN)_6$ and 22.00 g. of $Na_2CO_3$ and dilute to 1 l. with distilled water. Keep in a dark bottle. Standardize the ferricyanide against the thiosulfate as follows: To 10 ml. of the $K_3Fe(CN)_6$ solution add 25 ml. of the acetic acid mixture (1.1.) and 1 ml. of potassium iodide solution (1.2.) A creamy orange precipitate will form at this point. Titrate with standard thiosulfate solution (1.4.), adding the starch solution just before reaching the end point. The normality of the ferricyanide solution is calculated from this titration value.

Check the sugar equivalent against a standard sugar solution (made up of the sugar to be determined). The standard sugar solution should contain 1.0 to 1.5 mg. per ml. of the sugar. Dextrose was used for this standardization and the procedure followed is the same as outlined below for citrus juices, starting with (2.3.) and omitting

(2.10.) One ml. of the ferricyanide solution (exactly 0.05 N) was found to be equivalent to 1.51 mg. of dextrose. Pritchett and Stevens reported the equivalence to be 1.585 mg. of dextrose per ml. of ferricyanide.

*2. Procedure*

2.1. Strain the juice sample through absorbent cotton to remove most of the suspended matter. In the case of sewage, filter the sample through qualitative filter paper.

2.2. In a large test tube (200 × 25 mm.) add 5 ml. of the filtered juice or waste and 2 ml. of 1:1 HCl and make up to about 20 ml. with water. Heat on a slow steam bath for 30 min. Neutralize with NaOH to the end point of phenolphthalein and dilute to 500 ml. Samples low in sugars should be diluted less. 10 ml. of the diluted sample should contain 6 to 10 mg. of reducing sugar.

2.3. Place 10 ml. of the diluted sample in a large test tube and add 10 ml. of the potassium ferricyanide solution (1.5.)

2.4. Heat in boiling water for exactly 20 min.

2.5. Cool rapidly under running water.

2.6. Wash into a small flask with 25 ml. of the acetic acid mixture (1.1.)

2.7. Add 1 ml. of potassium iodide solution (1.2.)

2.8. Titrate with sodium thiosulfate (1.4.) to a faint yellow color.

2.9. Add 1 ml. of starch solution (1.3.) and complete the titration to the appearance of a white color. (Note: the solution is not clear at this point, as in most iodimetric titrations, but the end point is very sharp, as the precipitate furnishes a perfectly white internal background for observing the disappearance of the blue color of the starch-iodine end point.)

2.10. Calculate the per cent total sugar from the amount of ferricyanide reduced and the dextrose equivalent of the ferricyanide.

## Method for Determining Reducing Sugars

Reducing sugars are determined exactly as outlined previously for total sugars, omitting step 2.2., neutralizing the juice or waste to the phenolphthalein end point with NaOH and diluting 5 ml. of the sample to 200 ml. instead of 500 ml. Samples low in sugar should be run without dilution.

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# DETERMINATION OF FAIR SEWAGE SERVICE CHARGES FOR INDUSTRIAL WASTES—A DISCUSSION *

By Thomas M. Niles

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Mr. Schroepfer has performed a valuable service to the profession in pointing out the way in which the fundamental principle put forward in the Joint Group Report may be applied in arriving at fair charges to industries.

As "fairness" involves payment of the share of total required revenues in proportion to the uses made and to the benefits received, the computation of a fair charge for one class of beneficiary must at the same time result in fairness to the other classes. Thus, Mr. Schroepfer's computation of fair charges to a major wet industry results, as well, in fair charges to the major dry industry, the small wet industry, and the typical residence. It also results in fair charges to undeveloped property, which, although not using the system, nevertheless is benefited and should contribute a fair share of the needed annual revenues.

In nearly all cases where the contributions of wastes by one or more industries materially affect the basis of design of the treatment facilities, special studies of the fair share of the total annual costs to be charged to the industries should be made.

A contract recently executed between the Sanitary District of Decatur, Ill., and the A. E. Staley Manufacturing Company, which contributes a high proportion of the total quantity, suspended solids, and B.O.D. for the entire district, provides for payment by Staley of charges computed by a method quite similar to that described by Mr. Schroepfer.

The contract calls for payment by the industry of its fair share of the total annual Sanitary District costs, including (1) operation, (2) rehabilitation and minor improvements, (3) administration, and (4) bonds and interest. Computations which included an analysis of the costs and benefits of the system resulted in the allocation of about 50 per cent of the total annual cost to use, and about 50 per cent to the public and property benefits.

The use portion of the total annual costs was broken down into the shares applicable to quantity, suspended solids, and B.O.D. Use charges to the industry, which include rates per million gallons of quantity and per thousand pounds of suspended solids and B.O.D., are computed quarterly, based on records of costs and determinations of the quantities and loads contributed by the industry in proportion to the totals for the district. The public and property charges to the industry are based on assessed valuation.

The methods of computing the rates and charges are subject to renegotiation in case of future changed conditions.

Prior to this agreement, the district, for many years, has obtained all of its required revenue from a tax levy,

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; St. Paul, Minn.; Oct. 8–11, 1951. The original paper was published in This Journal, 23, 12, 1493 (Dec., 1951).

**TABLE I.—Allocation of Fair Value of Water System to Use and Benefit Classifications**

| Item | Fair Value or Amount | Per Cent Caused By | | | | Amount of Fair Value Caused By | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fire Protection | Public | Use | Property | Fire Protection | Public | Use | Property |
| Intake: | | | | | | | | | |
| Crib | $ 300,000 | 0 | 5.0 | 31.7 | 63.3 | $ 0 | $ 15,000 | $ 95,000 | $ 190,000 |
| Intake pipe | 1,200,000 | 0 | 5.0 | 31.7 | 63.3 | 0 | 60,000 | 380,000 | 760,000 |
| Low-lift pump. sta.: | | | | | | | | | |
| Structure | 350,000 | 0 | 5.0 | 31.7 | 63.3 | 0 | 17,500 | 110,800 | 221,700 |
| Equipment | 300,000 | 0 | 5.0 | 76.0 | 19.0 | 0 | 15,000 | 228,000 | 57,000 |
| Force main to filt. plant | 1,000,000 | 0 | 5.0 | 31.7 | 63.3 | 0 | 50,000 | 317,000 | 633,000 |
| Filtration plant: | | | | | | | | | |
| Pretreatment, chem. bldg.: | | | | | | | | | |
| Structures | 400,000 | 0 | 5.0 | 31.7 | 63.3 | 0 | 20,000 | 127,000 | 253,000 |
| Equipment | 80,000 | 0 | 5.0 | 76.0 | 19.0 | 0 | 4,000 | 61,000 | 15,000 |
| Sed. basins and filters: | | | | | | | | | |
| Structures | 1,000,000 | 0 | 5.0 | 31.7 | 63.3 | 0 | 50,000 | 317,000 | 633,000 |
| Equipment | 320,000 | 0 | 5.0 | 76.0 | 19.0 | 0 | 16,000 | 243,000 | 61,000 |
| Filtered water res. | 500,000 | 50.0 | 5.0 | 30.0 | 15.0 | 250,000 | 25,000 | 150,000 | 75,000 |
| Elevated storage | 100,000 | 50.0 | 5.0 | 40.0 | 5.0 | 50,000 | 5,000 | 40,000 | 5,000 |
| High-lift pump. sta.: | | | | | | | | | |
| Structures | 330,000 | 50.0 | 5.0 | 15.0 | 30.0 | 165,000 | 16,500 | 49,500 | 99,000 |
| Equipment | 420,000 | 50.0 | 5.0 | 40.0 | 5.0 | 210,000 | 21,000 | 168,000 | 21,000 |
| Feeder mains, over 24 in. | 3,250,000 | 40.0 | 5.0 | 44.0 | 11.0 | 1,300,000 | 162,000 | 1,430,500 | 357,500 |
| Distribution system: | | | | | | | | | |
| Pipe 24 to >12 in. | 1,300,000 | 50.0 | 5.0 | 36.0 | 9.0 | 650,000 | 65,000 | 468,000 | 117,000 |
| Pipe 12 to 8 in. | 1,800,000 | 50.0 | 5.0 | 36.0 | 9.0 | 900,000 | 90,000 | 648,000 | 162,000 |
| Pipe 6 in. | 3,800,000 | 50.0 | 5.0 | 36.0 | 9.0 | 1,900,000 | 190,000 | 1,368,000 | 342,000 |
| Pipe <6 in. | 150,000 | 0 | 5.0 | 95.0 | .0 | 0 | 7,500 | 142,500 | 0 |
| Meters | 250,000 | 0 | 5.0 | 95.0 | .0 | 0 | 12,500 | 237,500 | 0 |
| Yards, equip. and stores | 2,000,000 | 20.0 | 5.0 | 70.0 | 5.0 | 400,000 | 100,000 | 1,400,000 | 100,000 |
| Total | $18,850,000 | — | — | — | — | $5,825,000 | $942,000 | $7,980,800 | $4,102,200 |
| Percentage | 100.0 | — | — | — | — | 30.9 | 5.0 | 42.3 | 21.8 |

**TABLE II.—Allocation of Annual Cost of Operation of Water System**

| Item | | Total Annual Amount | Per Cent Caused By | | | | Amount Caused By | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Description | | Fire Protection | Public | Use | Property | Fire Protection | Public | Use | Property |
| 1 | Intake | $ 4,000 | 0 | 5.0 | 31.7 | 63.3 | $ 0 | $ 200 | $ 1,300 | $ 2,500 |
| 2 | Low-lift pump. station: | | | | | | | | | |
| | Labor | 42,000 | 0 | 5.0 | 85.0 | 10.0 | 0 | 2,100 | 35,700 | 4,200 |
| | Power | 48,000 | 0 | 5.0 | 63.3 | 31.7 | 0 | 2,400 | 30,400 | 15,200 |
| | Other | 8,000 | 0 | 5.0 | 63.3 | 31.7 | 0 | 400 | 5,100 | 2,500 |
| 3 | Force main to filt. plant | 3,000 | 0 | 5.0 | 63.3 | 31.7 | 0 | 150 | 1,900 | 950 |
| 4 | Filtration plant: | | | | | | | | | |
| | Labor | 80,000 | 0 | 5.0 | 85.0 | 10.0 | 0 | 4,000 | 68,000 | 8,000 |
| | Power | 8,000 | 0 | 5.0 | 75.0 | 20.0 | 0 | 400 | 6,000 | 1,600 |
| | Chem. and supplies | 120,000 | 0 | 5.0 | 75.0 | 20.0 | 0 | 6,000 | 90,000 | 24,000 |
| | Other | 15,000 | 0 | 5.0 | 75.0 | 20.0 | 0 | 750 | 11,250 | 3,000 |
| 5 | Storage works | 4,000 | 50.0 | 5.0 | 40.0 | 5.0 | 2,000 | 200 | 1,600 | 200 |
| 6 | High-lift pump. station: | | | | | | | | | |
| | Labor | 58,000 | 50.0 | 5.0 | 40.0 | 5.0 | 29,000 | 2,900 | 23,200 | 2,900 |
| | Power | 135,000 | 50.0 | 5.0 | 36.0 | 9.0 | 67,500 | 6,750 | 48,600 | 12,150 |
| | Other | 12,000 | 50.0 | 5.0 | 36.0 | 9.0 | 6,000 | 600 | 4,300 | 1,100 |
| 7 | Distribution system: | | | | | | | | | |
| | Mains | 150,000 | 50.0 | 5.0 | 40.0 | 5.0 | 75,000 | 7,500 | 60,000 | 7,500 |
| | Meters | 300,000 | 0 | 5.0 | 75.0 | 20.0 | 0 | 15,000 | 225,000 | 60,000 |
| 8 | Yards, equip. and stores | 50,000 | 20.0 | 5.0 | 60.0 | 15.0 | 10,000 | 2,500 | 30,000 | 7,500 |
| | Sub-total | $1,037,000 | 18.3 | 5.0 | 62.0 | 14.7 | $189,500 | $51,850 | $642,350 | $153,300 |
| 9 | Administration[1] | 350,000 | 18.3 | 5.0 | 62.0 | 14.7 | 64,000 | 17,500 | 217,000 | 51,500 |
| | Sub-total | $1,387,000 | 18.3 | 5.0 | 62.0 | 14.7 | $253,500 | $69,350 | $859,350 | $204,800 |
| 10 | Debt service[2] | 1,037,000 | — | — | — | — | | | | |
| | Total | $2,424,000 | — | — | — | — | | | | |

[1] Allocated in proportion to the sums of all other items.
[2] $18,850,000 at 5.5 per cent.

**TABLE III.—Allocation of Debt Service of Water System**

| Item | Proportioned Amount | Per Cent | Annual Debt Service at 5.5 Per Cent |
|---|---|---|---|
| Fire protection | $5,825,000 | 30.9 | $320,000 |
| Public | 942,000 | 5.0 | 52,000 |
| Use | 7,980,800 | 42.3 | 439,000 |
| Property | 4,102,200 | 21.8 | 226,000 |
| Total | $18,850,000 | 100.0 | $1,037,000 |

of which the share paid by this industry is about $8,000 annually (about 7 per cent of the total). Under the new contract, the total payment will approach $35,000. Had the charge been based on proportionate use alone, without regard to property benefits, it would have been in the neighborhood of double this amount. Neither extreme is fair.

As the fundamental consideration of fairness in rates applies equally to water and sewage, it is of interest to apply procedures similar to those used by Mr. Schroepfer to the computation of fair charges for use and benefits received by similar typical examples in connection with the water system.

Tables I, II, III, and IV present computations, for a typical large water system, of the shares of the total annual required revenue that should be charged to fire protection, the public, users, and properties. These computations have been made for a much larger community than the one used by Mr. Schroepfer, but percentagewise and from the standpoint of unit rates the differences are not great.

Briefly, the system studied has the following pertinent characteristics:

**TABLE IV.—Allocation of Total Annual Cost of Water System**

| Item | Total | Share of Each Major Interest | | | |
|---|---|---|---|---|---|
| | | Fire Prot. | Public | Users | Properties |
| Per cent: | | | | | |
| Admin. and oper. | 100.0 | 18.3 | 5.0 | 62.0 | 14.7 |
| Debt service | 100.0 | 30.9 | 5.0 | 42.3 | 21.8 |
| Share: | | | | | |
| Admin. and oper. | $1,387,000 | $253,500 | $69,350 | $859,350 | $204,800 |
| Debt service | 1,037,000 | 320,000 | 52,000 | 439,000 | 226,000 |
| Total | $2,424,000 | $573,500 | $121,350 | $1,298,350 | $430,800 |
| Composite per cent | 100.0 | 23.6 | 5.0 | 53.6 | 17.8 |

*Computation of Three-Part Rate*

Assessed valuation

| | |
|---|---|
| Buildings or structures | $300,000,000 |
| Land | 150,000,000 |
| Total | $450,000,000 |

1. Fire protection—to structures

$$\frac{573{,}500}{300{,}000} = \$1.91;\ \text{say } \$1.90 \text{ per } \$1{,}000.$$

2. The public and property

$$\frac{121{,}350 + 430{,}800}{552{,}150 \div 450{,}000} = \$1.23;$$

say $1.25 per $1,000.

3. Quantity charge

60.0 m.g.d., of which 48.0 m.g.d. is metered.

$48{,}000{,}000 \times 365 = 17{,}520{,}000$ M gal.

$$\frac{1{,}298{,}350}{17{,}520{,}000\ \text{M}} = 7.4¢ \text{ per M gal.}$$

(This is the average charge per 1,000 gal. and this average should be made into a rate structure.)

| | |
|---|---|
| Total fair value or amount | $18,850,000 |
| Annual debt service | $ 1,037,000 |
| Annual cost of operation | 1,387,000 |
| Total annual revenue required | $ 2,424,000 |
| Assessed valuation: | |
| Buildings | $300,000,000 |
| Land | 150,000,000 |
| Total | $450,000,000 |
| Total metered water | 17,520 m.g./year |

Table I shows the computations by which the total fair value, itemized as to major parts of the works, has been allocated to the four use and benefit classifications. The resulting percentages, which apply also to fixed charges as shown in Table III, are as follows:

| | |
|---|---|
| Fire protection | 30.9% |
| Public benefit | 5.0% |
| Use | 42.3% |
| Property benefit | 21.8% |
| Total | 100.0% |

Table II shows similar computations for operating costs, which result in the following percentage allocations:

| | |
|---|---|
| Fire protection | 18.3% |
| Public benefit | 5.0% |
| Use | 62.0% |
| Property benefit | 14.7% |
| Total | 100.0% |

Table IV shows the combined per cent and share of each major interest and beneficiary in the total annual cost and results in the following allocations:

| Description | Share of Total Annual Required Revenue | |
|---|---|---|
| | Amount | Per Cent |
| Fire protection | $573,500 | 23.6 |
| Public benefit | 121,350 | 5.0 |
| Use | 1,298,350 | 53.6 |
| Property benefit | 430,800 | 17.8 |
| Total | $2,424,000 | 100.0 |

Also shown in Table IV are the computations of a three-part rate, resulting in the following unit charges:

1. Fire protection, charged to structures, at $1.90 per $1,000 of assessed valuation of structures.
2. Public benefit and property charge, to property, at $1.25 per $1,000 of total assessed valuation.
3. Quantity charge, at average rate of $0.074 per 1,000 gal.

For application to the various classes of beneficiaries in the examples which follow, the average quantity charge is assumed to be spread over three brackets ranging from a high bracket of $0.10 per 1,000 gal. to a low rate of $0.05 per 1,000 gal.

The examples for which comparative computations of charges by different methods are made are as follows:

| Description | Assessed Valuation ($) | | Water Used (1,000 gal./yr.) |
|---|---|---|---|
| | Buildings | Total | |
| Major wet industry | 400,000 | 500,000 | 274,000 |
| Major dry industry | 400,000 | 500,000 | 1,830 |
| Small wet industry | 70,000 | 80,000 | 36,500 |
| Residence | 4,000 | 5,000 | 108 |

Four methods of charges for water use and benefits are compared as follows:

*Method 1.*—All on general property tax.

$$\text{Charge} = \frac{\$2,474,000}{450,000} = \$5.40 \text{ per } \$1,000.$$

*Method 2.*—All on quantity of water used.

$$\text{Average charge} = \frac{\$2,474,000}{17,520,000} = \$0.14 \text{ per } 1,000 \text{ gal.}$$

| | |
|---|---|
| High bracket | $0.19 per 1,000 gal. |
| Intermediate bracket | $0.14 per 1,000 gal. |
| Low bracket | $0.09 per 1,000 gal. |

*Method 3.*—24 per cent to fire protection on general tax, 76 per cent on quantity of water used.

$$\text{Fire protection} = \frac{\$584{,}000}{450{,}000}$$

$$= \$1.30 \text{ per } \$1{,}000.$$

Average quantity charge

$$= \frac{\$1{,}840{,}000}{17{,}520{,}000} = \$0.105 \text{ per } 1{,}000 \text{ gal.}$$

| | |
|---|---|
| High bracket | $0.14 per 1,000 gal. |
| Intermediate bracket | $0.105 per 1,000 gal. |
| Low bracket | $0.07 per 1,000 gal. |

*Method 4.*—As computed for Joint Group method.

| | |
|---|---|
| Fire protection | $1.90 per $1,000 of structures |
| Public and property | $1.25 per $1,000 of total |

Use:

| | |
|---|---|
| High bracket | $0.10 per 1,000 gal. |
| Intermediate bracket | $0.074 per 1,000 gal. |
| Low bracket | $0.05 per 1,000 gal. |

Applying each of the four methods to each of the typical examples results in the following annual charges:

| Method | Major Wet Industry | Major Dry Industry | Small Wet Industry | Residence |
|---|---|---|---|---|
| 1 | $ 2,700 | $2,700 | $ 430 | $27.00 |
| 2 | 24,600 | 256 | 3,300 | 20.50 |
| 3 | 18,850 | 842 | 2,654 | 21.60 |
| 4 | 15,085 | 1,521 | 2,063 | 24.65 |

The total annual charges for each example under the four alternate methods are shown graphically in Figure 1.

As for fire protection, the illustration is considered to be reasonably correct as regards the computation of the amount that should be charged for this benefit. The application of the charge to valuation of structures, rather than to total valuation, is believed to be a step in the right direction, but is not in itself entirely fair, as it does not take into account such factors, among others, as relative structure hazards, value and hazard of contents, and decreased fire demands for sprinkler installations.

For either water or sewage charges, it must be borne in mind that local conditions will affect the computation of the shares to be charged to users and to properties. Also, it may be expected that the conditions will not remain static, and that from time to time the allocations should be restudied and proper adjustments made.

Mr. Schroepfer shows, by his tabulation and diagram, that there are important differences in the amounts of the sewage charges when computed by several alternate methods. The ranges, expressed in percentages of the Joint Group amounts, are as follows:

1. For the residence: from a minimum, based on B.O.D., of 94 per cent to a maximum of 500 per cent if based on taxes, with the quantity basis 160 per cent.

2. For the major wet industry: from 12 per cent if based on property tax to 200 per cent if based on B.O.D. In this case, the quantity basis is about the same, or 97 per cent.

3. For the major dry industry: from 6 per cent if based on B.O.D. to nearly 300 per cent if based on property tax alone. On the quantity basis, the charge would be 16 per cent of that considered fair.

4. For the small wet industry: from 10 per cent for the property tax basis to 275 per cent for the incremental B.O.D. basis, with the quantity basis at about 65 per cent.

Because they most nearly represent sound application of the fundamental principle, charges computed by the Joint Group method are considered to be the closest approach to fairness. Departures from this method result in substantial differences, and the other

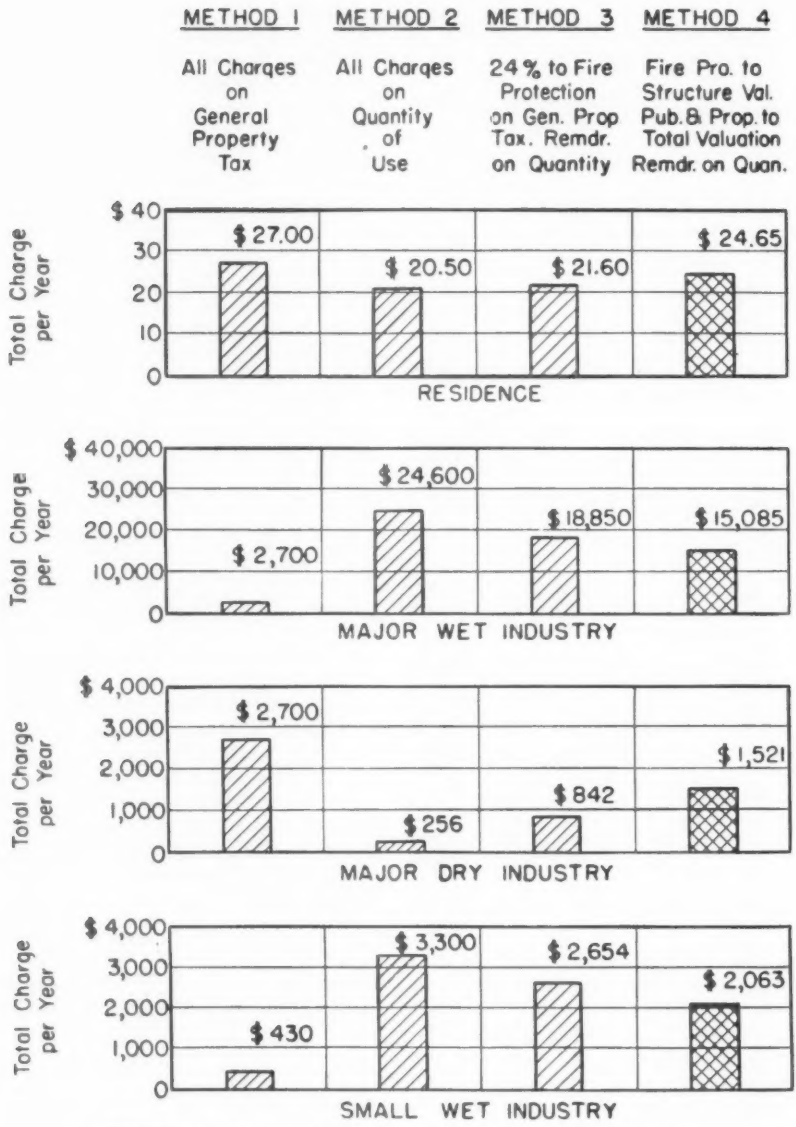


FIGURE 1.—Comparative water charges by four alternate methods. (See text for description of charge bases.)

methods may be considered unfair to the degree that they result in such departures.

Under present enabling acts, it is not always possible to make a separate direct charge to property, as in a good many cases the charges are limited to the actual users of the system. Where this is true, a fair allocation of contributions as between users and property may involve payment of the property portion by the city out of general tax revenues, with only the use portion billed directly as a sewage charge.

The somewhat limited experience to date in the application of the fundamental principle put forth by the Joint Group has brought out a willingness on the part of industries to cooperate, and a recognition of its inherent fairness. With this the case, it may be expected that ways will be found, possibly through improved legislation where needed, to permit its more general use.

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## FINAL REPORT ON SCHUYLKILL RIVER CLEAN-UP

Under date of July 1, 1951, the consulting engineers for the Schuylkill River desilting project have submitted their final report on the project to the Pennsylvania authorities, for whom the work was done. The engineering group included the consulting firms of F. R. Harris–F. H. Dechant Associates; Day & Zimmerman, Inc.; Albright & Friel, Inc.; and Justin & Courtney—as joint venturers for the Commonwealth of Pennsylvania under the name of Schuylkill River Project Engineers.

The project is probably one of the most unusual stream clean-up programs ever attempted on an entire watershed. The accumulation of anthracite culm over a 100-year period rendered the river unsightly, subject to high flood stages, and generally grossly contaminated, as well as unusable for the navigational and recreational uses formerly associated with it. Removal of these deposits (some 38,000,000 tons) from the river channel and banks and old damsites along the river, plus removal of several old dams and construction of new dams or reconstruction of old dams, when combined with pollution abatement and prevention activities under the jurisdiction of the Sanitary Water Board, will eliminate the unsightly and hazardous conditions.

The project cost reported in the final report is $31,784,744.11, not including the cost of operating management of the project. Besides channel cleaning and improvement, desilting basins have been constructed with a viewpoint to removing further silt from the river at strategic points along its course, thus cleaning up the lower stretches. Included in the cost are maintenance facilities for this purpose, including necessary dredges and other plant.

# Stream Pollution

## NATIONAL WATER RESOURCES POLICY AS RELATED TO STREAM POLLUTION *

By L. R. Howson

*Partner, Alvord, Burdick and Howson, Consulting Engineers, Chicago, Ill.*

It would appear that in defining the relationship between national water resources policy and stream pollution, several questions should be answered, as follows:

1. How serious is stream pollution?
2. Are present controls over stream pollution adequate and if not, why not?
3. At what governmental level should stream pollution be controlled?
4. At whose expense should pollution reduction be made?

### How Serious is Stream Pollution?

Undoubtedly stream pollution exists and to an important extent. In the recent report of the President's National Water Policy Commission, reference is made to the pollution conditions disclosed by the U. S. Public Health Service in its survey of 11 major river valleys said to be selected to be representative over the country as a whole. From this review the Commission concluded:

1. Even though not all streams are polluted, the major streams are gravely affected and the problem is nationwide.
2. Pollution is a factor that already affects or eventually will affect all water resources development, whether it be for flood control, irrigation, hydroelectric power, municipal and industrial use, or recreation.

This survey covered 4,409 municipalities and 3,413 industrial plants. Forty-three per cent of the cities and 57 per cent of the industries were discharging untreated wastes, and 800 of the treatment plants were overloaded or inadequate.

But there is another side of the picture. Sewage and waste disposal really had their inception about the turn of the century. By 1920 there were 1,000 municipal sewage treatment plants in the United States handling wastes from approximately 10,000,000 people; 18 per cent of the urban population then had some form of sewage treatment. Figure 1 shows the growth in U. S. urban population and that part of it provided with sewage treatment facilities. The number of treatment plants increased to approximately 2,400 in the next decade and 18,000,000, or more than 35 per cent, of the urban population was then tributary to sewage treatment plants.

In the next two decades, which embraced the longest depression in U. S. history and World War II, the number of sewage plants more than doubled and the population served tripled. As of 1950, approximately 60,000,000 people were tributary to more than 6,700 sewage treatment plants and 65 per cent of the urban population of the United States had some form of waste treatment. Figure 2 shows the growth in the number of municipal waste treatment plants and the percentage of urban population having waste treatment.

Assuming, for illustration, that the waste treatment plants have an overall B.O.D. efficiency of 66⅔ per cent,

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; St. Paul, Minn.; Oct. 8–11, 1951.

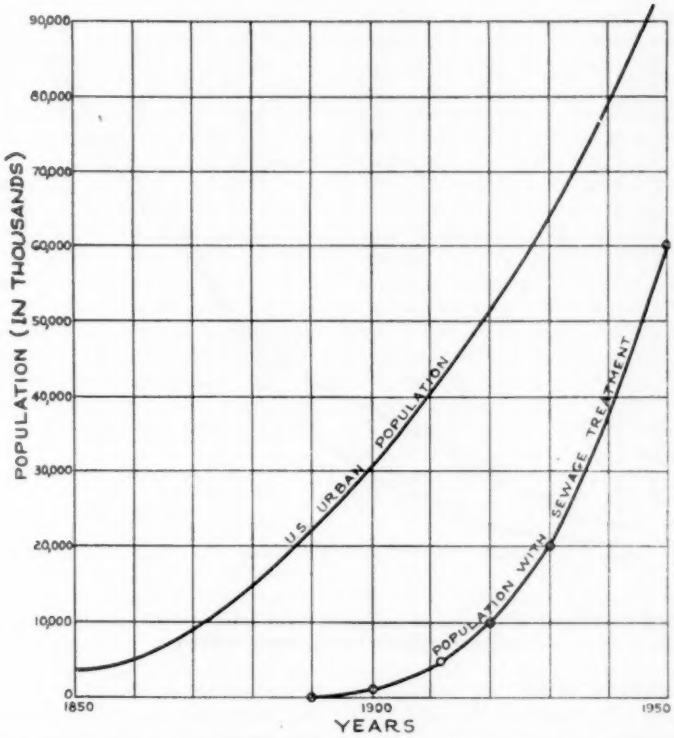


**FIGURE 1.—Growth in U. S. urban population and population provided with sewage treatment facilities.**

that is equivalent to saying that 40,000,000 people in the U. S. are now receiving complete sewage treatment.

The accelerated rate of sewage treatment is reflected in the following figures:

| Decade | Additional Population Having Sewage Treatment |
|---|---|
| Prior to 1900 | 1,000,000 |
| 1900–1910 | 3,000,000 |
| 1910–1920 | 5,500,000 |
| 1920–1930 | 8,500,000 |
| 1930–1940 | 19,000,000 |
| 1940–1950 | 23,000,000 |

If this accelerated rate should continue, another couple of decades would complete the job. Truly, much has been accomplished.

The extent to which sewage treatment has progressed is, however, not universal, and entire rivers, like the Ohio, the Connecticut, and others, have had substantially no reduction in pollution load during this period when in the U. S. as a whole, progress has been rapid. On these streams, pollution is still serious and must be corrected.

It should also be pointed out that due to the continually increasing percentage of people that live in cities, as well as the over-all population growth, the urban population has doubled in the last 35 years and is currently increasing at the rate of ap-

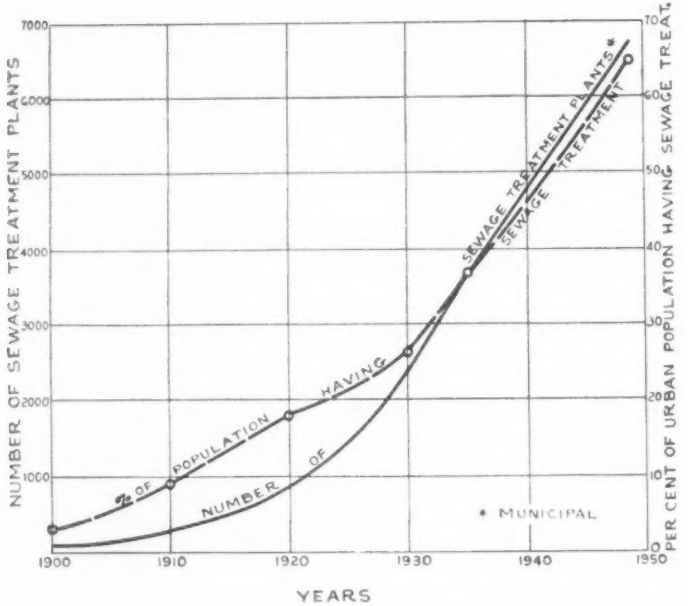


**FIGURE 2.—Growth in number of municipal waste treatment plants and percentage of urban population having waste treatment.**

proximately 1,500,000 per year. New facilities will, therefore, be needed for this growth.

Also, as the population density increases the degree of treatment must be stepped up.

The sum of these two requirements illustrates the continuing need for additional treatment facilities, a fact which has been reflected in waterworks expenditures over the last quarter century increasing at a rate 2½ times as fast as the population.

### Are Present Pollution Controls Adequate?

It is believed the answer to the question about adequacy of present stream pollution controls is generally in the affirmative, and that the responsibility for the correction of conditions which are now bad due to failure to keep up with the national trend in sewage treatment or pollution abatement, is largely because of the apathy of the contributing communities. When community filth becomes a personal matter, something will be done about it.

Industrial waste disposal, too, will make better progress as the public cares for its wastes. Education of the public and research for industry are essential steps to continued progress, the speed of which will ultimately depend upon the will of the people to clean up the streams.

At the beginning of the 50-year period, during which 60,000,000 people have provided themselves with waste treatment facilities, there were few statutes relating to pollution. Installations were largely made for their direct benefit to the local community. When local pollution was corrected it was frequently found that conditions were still not satisfactory, due to the failure of others to likewise clean up. This led to the adoption of regulatory

statutes by which, in most states, some agency such as the Department of Public Health, could investigate pollution and order corrective measures. That this procedure has been adequate and wisely administered is evidenced by the cooperation secured. As a result, in the last 15-year period, the wastes of 30,000,000 people were provided with treatment, a number equal to that remaining without treatment at this time.

Yes, the patient efforts and educational work in the several states have been effective. It is believed that present controls, modified in the future to meet changing needs, as they have been in the past, will continue to be adequate.

### Level of Pollution Control

The question continually arises as to whether the Federal Government should exercise control over the pollution of waterways and to what extent, if any, it should subsidize the cost of waste treatment. Congress, in 1948, passed the Water Pollution Control Act establishing a policy which recognized the primary responsibility and rights of the states in controlling water pollution. The Act further provides a relatively minor annual appropriation of $22,500,000 for loans to states, municipalities, or interstate agencies for the construction of necessary sewage treatment works. The Act also authorizes an appropriation of $1,000,000 a year to states for conducting investigations, research, and surveys relating to the prevention and control of water pollution caused by industrial wastes. A third appropriation of $1,000,000 a year is made as a grant to states, municipalities, or interstate agencies to aid in financing the cost of engineering investigations and other action preliminary to the construction of projects approved by the appropriate state water agency and the Surgeon General.

The Federal Water Pollution Control Act has no original enforcement powers, but with the consent of the water pollution agency of the state where the pollution occurs, the Attorney General of the U. S. may be requested to bring suit against the offender.

The Water Pollution Control Act of 1948 is discussed by the President's Water Resources Policy Commission in its recent report, "A Water Policy for the American People." The Commission recommended that the Pollution Control Act be thoroughly tested, that the appropriation for the administrative and regulatory activities of the Public Health Service be increased, and that funds for federal loans to municipalities and other public bodies and industries at not more than 2 per cent interest be available sufficient to cover the entire amounts required for constructing sewage and waste treatment plants.

The Commission further recommended that, "Plans for construction of waste treatment plants, whether municipal or industrial, should include reasonable provision for:

(a) Making organic materials in waste available for use.
(b) Utilizing by-product gas.
(c) Reclaiming valuable minerals.
(d) Processing the discharged water for re-use by industry or recharging ground water."

The Commission further recommended that "if the Federal-state-local cooperative pollution program fails to provide the country with clear rivers within a period of 10 years, the 1948 act should be reconsidered with a view to providing for Federal enforcement."

Several aspects of these recommendations are worthy of further consideration. First, is that relating to time. It is believed unreasonable to predicate federal enforcement upon the failure of present controls "to provide the country with clean rivers within a period of 10 years." The pollution

cleanup, as hereinbefore shown, has been proceeding at a rapid and continually accelerated rate. It is believed it ought to proceed along these evolutionary lines under present controls, rather than the revolutionary line suggested by the 10-year ultimatum.

Federal jurisdiction should be limited to the administration of existing laws and to research and guidance to the states and local government, so that pollution control shall be as uniform as practicable under the variable conditions encountered.

The President's Commission report in its statement quoted with respect to reclamation, amplified further in the text, apparently disregards economic considerations. It makes the statement that "More than 18 million tons of sludge are destroyed annually, and (based on the $2 a ton removal rate paid in the nation's capital) at least 36 million dollars is paid for its removal. If packaged and sold instead of being dumped or burned, this sludge would gross nearly 400 million dollars a year, net a profit to the cities, and return a valuable fertilizer to the soil." The writer firmly believes, that if packaging and selling of fertilizer is tied into future sewage treatment projects it would be a serious deterrent to the present high rate of plant construction. In most cases, sludge cannot be packaged and sold except at a material economic loss.

The reason that only two or three cities, as stated in the President's Commission report, are practicing the recovery of sewage plant effluent is again evidence of the economics of the situation. To require such re-use as a prerequisite for the approval of construction of waste treatment plants or prospective loans or grants for such construction would surely retard progress.

Let us be realistic, recognizing that although sludge and effluent may have some value in individual cases, in the vast majority of cases any revenue therefrom can only be secured by expenditures materially in excess of the revenues. While the possibility should be explored in each case, it is wise to stay on reasonably sound economic ground and not resort to propaganda and hysteria to solve sanitary difficulties.

In this connection, such propaganda as was shown in a national magazine some months ago, in which water in a drinking glass was labeled, "Filthy, but you drink it," is highly misleading. The title might more appropriately have advised the public how instrumental improved sanitation has been in prolonging life under some such caption as, "Man alive—you might have been dead." The positive accomplishments of improved water purification, sewage treatment, and sanitation in general have saved millions of lives. Sanitation in the future can progress along sound, esthetic, and economic lines.

The President's Commission recommends that funds for federal loans to municipalities, other public bodies, and industries be available at not more than 2 per cent interest covering the entire amounts required to construct sewage and waste treatment works. The Federal Government would then be in the position of a banker responsible for the safety of his loans. They should only be made for constructing works for the benefit of a limited number under terms equitable to all other citizens of the nation. These loans should, therefore, be repaid in full with interest within a period shorter than the useful life of the works. The interest rate should be such that the Federal Government will fully recoup all costs, including those of administration.

It should be pointed out that waste treatment is within the economic reach of anyone that wants it. By and large, practically any community in the U. S. that wants sewage treatment can finance it at a cost of approximately 1¢ per capita per day, which will pro-

duce a sum sufficient to provide for the interest and amortization of the cost and the expense of operating the treatment plant. If waste treatment cannot be sold at so low a cost, people have not been sufficiently educated either as to the requirements or the cost.

Grants in whole or in part ought not to be made by the Federal Government for waste disposal.

In the opinion of the author, the biggest deterrent to the cleaning up of some of the worst polluted streams is the idea that possibly if conditions get bad enough the Federal Government will put up part of the money necessary to clean up the rivers. Wastes are contributed locally; they should be abated locally and at the cost of the people that create them.

### Who Should Finance Sewage Treatment?

So far as is known to the writer, no single pollution problem is nationwide or its solution of national interest. Each is essentially local, affecting at most a few states.

Although pollution may be more or less universal in its distribution, each instance and its correction are local. It is believed economically sound that each pollution problem should be solved at the lowest governmental level which exercises jurisdiction over the watercourse being polluted. In most cases that is the local municipality. In others, it becomes a group of municipalities, frequently organized as a sanitary district. In still others, it embraces an entire drainage area and that, in a comparatively few cases, necessitates interstate compacts.

### Summary

In summary, it is believed that a sound national water policy as related to stream pollution should recognize that:

1. Although approximately two-thirds of the urban population of the U. S. is now provided with sewage treatment facilities, serious stream pollution persists.

2. Excellent progress has been made in waste treatment, both municipal and industrial, under the present system of controls. Such controls are believed adequate and should be continued.

3. Stream pollution should be controlled at the lowest practicable level of government having jurisdiction over the stream.

4. Sewage treatment should be provided by and at the expense of those contributing the pollution. In general, municipal waste treatment can be provided at a cost of approximately 1¢ per capita per day.

5. Federal loans should only be made on projects of limited benefit on terms which are fair to all other citizens. This requires that the loan be fully repaid within a period shorter than the life of the facilities and that the interest be sufficient to cover all costs incurred by the Federal Government, including administration.

6. Greater speed in accomplishing the complete cleanup will be realized if the approval of future construction is not predicated upon questionable fringe reclamation benefits. Pollution abatement and waste treatment are essentially economic problems.

7. Control of pollution and the responsibility for its correction now lie primarily in the states, where it should remain. The Federal Government should confine its efforts to administration of existing laws, to research, and to guidance to the states and political subdivisions in the formulation and enforcement of regulations having as much uniformity as is consistent with the variable conditions encountered.

# THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

## INITIAL OPERATION OF TWO-STAGE HIGH-RATE TRICKLING FILTER PLANT AT MECHANICSBURG, PA. *

BY HARRY C. FOTH

*Superintendent of Sewers, Mechanicsburg, Pa.*

On September 13, 1950, the Borough of Mechanicsburg, Pa., started operation of a new sewer system and sewage treatment plant, built by the Mechanicsburg Municipal Authority at a cost of approximately $1,100,000 and financed by a bond issue of $1,250,000. Revenues from the connection fees and yearly rentals are to provide sufficient income to pay all operating expenses and to retire the bond issue in about 40 years. Operation is controlled by the Borough Council under a lease-back arrangement. Operation of the plant started with a very few residential connections (130 as of Sept. 30, 1950). A year later about 800 out of a possible 2,000 connections had been made.

The gravity collection system consists of approximately 17 mi. of clay pipe, ranging in size from 8-in. laterals to 18-in. interceptors. Depth of mains varies from 5 to 22 ft., with a very high percentage of rock being encountered during trenching operations.

The treatment plant is located west of the Borough on part of a 22-acre tract purchased by the Authority. About 5.5 acres are used by the plant, the balance being rented on a cash basis to a neighboring farmer. This eliminates the expense of keeping the extra acreage mowed and provides some additional cash income. The effluent is discharged into Trindle Run, which is a very small stream but has a fairly steady year-round flow. Because of the small receiving stream, a high degree of treatment was considered necessary. Property owners along the first few miles of the stream voiced objections to the possible contamination of wells and drinking water for their cattle by the treated effluent. However, tests of such waters were made by the engineers of the Authority and the State Health Department prior to the completion of construction; all the wells so tested were found to be more or less contaminated by sewage bacteria, due to raw sewage entering the underground streams from the sinks and cesspools in the town. It will be interesting to note in the future if the construction of a sewage works has reduced the pollution of the underground streams.

### Treatment Plant Design

The Borough of Mechanicsburg has a present population of 6,900, most of whom work in nearby towns. The only industrial wastes sent to the plant at present are contributed by a dairy producing ice cream and condensed milk, one commercial laundry, and one Laundromat. A service station and a res-

* Presented at 1951 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1951.

taurant, situated about 1 mi. out of town, send their sewage to the town system through their own force main, which empties into one of the smaller interceptors. Otherwise, all sewage is domestic.

The plant was designed to handle an average flow of 0.64 m.g.d. and a peak rate of 1.4 m.g.d., with the expectation that the borough would have a population of 8,000 in 1970, plus a population equivalent of 1,800 persons for the dairy. The dairy has changed its piping so that all non-contaminated cooling water is separated from the contaminated water and disposed of through a separate storm sewer system, to reduce the volume of waste discharged to the sewage plant. With the present population of 6,900, it is expected that the normal daily total flow will be less than 0.5 m.g.d. At present, with 800 connections completed and the industrials included, the average flow is about 0.225 m.g.d.

Only two full-time employees are used—the superintendent, who is also the plant operator, and an assistant, who issues connection permits and notices, collects and accounts for the connection fees and rentals, and performs the duties of plumbing inspector. Such incidental labor as is required about the plant is drawn from the Borough forces as needed. Because the plant is fully equipped with automatic controls and an alarm system described later, it is as nearly a one-man operation as can be devised under present knowledge and conditions.

## Treatment Plant Units

Sewage from the town comes to the plant wet well by gravity through an 18-in. interceptor. Sewage flows are measured with a Parshall flume ahead of the wet well and recorded on an instrument located in the office on the upper floor of the control building.

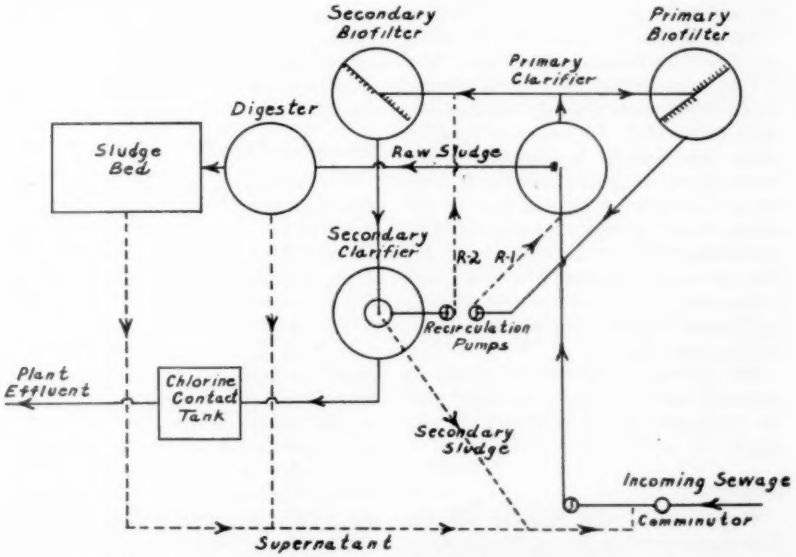


FIGURE 1.—Flow diagram of Mechanicsburg, Pa., sewage treatment plant.

Poor measurements were obtained initially—until concrete chips and debris were removed from the float pit and connecting pipes.

A comminutor and a by-pass bar screen are located between the Parshall flume and the wet well proper. As constructed, air changes in the wet well were secured through a turbine-type thermal ventilator in the roof covering the wet well. This ventilator did not accomplish its purpose, as it was too high above the floor level. A motor-driven exhaust fan with a duct reaching to within 1 ft. of the floor was installed to provide a positive change of air, thereby making the wet well safe for the operator to work in at any time.

The raw sewage is pumped from the wet well to the primary clarifier by any one or more of three short-coupled centrifugal pumps located in the lower basement of the control building. One pump is of 400-g.p.m. and the other two each of 600-g.p.m. capacity. One of the large units is for stand-by purposes. Repacking of these pumps, which discharge to a common header, is not a serious problem; but the short coupling does make it an awkward one. A coupling shaft 6 in. to 1 ft. longer would very much simplify the replacement of packing. In order to equalize wear, the controls are shifted every two or three weeks, alternating the use of the stand-by pump with one of the others, ensuring that all pumps will be in working order in case of emergency. The dry well is equipped with a small sump pump, which takes care of seepage, pump leakage, and water used in washing the floor.

The primary clarifier is 45 ft. in diameter and 9 ft. deep, allowing a 2-hr. detention period at a flow of 1.34 m.g.d.

*Biofilters*

Weirs divide the clarifier effluent flow, sending 500 g.p.m. to the primary biofilter and the balance to the secondary biofilter. The primary filter is 60 ft. in diameter, is equipped with a two-arm rotary distributor, and has a dosing rate of 10.8 m.g.a.d. at a flow rate of 0.7 m.g.d. After four months of operation, this filter began to show the sought-after green color of a healthy active condition.

When first started, the center column of this filter showed a leak in the concrete structure. After investigation, it was agreed that the leak might soon be sealed by deposits of sewage solids in the concrete. This has evidently been the case, as no further signs of leakage have shown up. Effluent from this filter is returned to the primary clarifier through a 500-g.p.m. recirculating pump.

The remaining primary clarifier effluent is drawn to the secondary biofilter to begin the second recirculation stage. The filter is 60 ft. in diameter, is equipped with a four-arm rotary distributor, and is operated with a dosing rate of 20.8 m.g.a.d. at a flow of 1.34 m.g.d. This filter has operated satisfactorily, except for the recent appearance of a few ponded areas, believed due to fine stone not being correctly spread when the filter media was placed.

*Secondary Clarifier*

The secondary clarifier has a 2-hr. detention period at a flow of 1.34 m.g.d. A 500-g.p.m. pump recirculates part of the effluent to the secondary biofilter. The remainder is discharged to the outfall stream after post-chlorination with 30-min. contact period.

Instead of pumping the light sludge from the final clarifier directly to the digester at stated intervals, the valve on the sludge line to the wet well is kept partially open at all times, so that this sludge is drawn back to the wet well and mixed with the incoming sewage. This underflow is estimated to be about 10 per cent of the total flow through the clarifier.

*Digester*

The digester, of the fixed-cover type, is 45 ft. in diameter and 19 ft. side water depth, providing 3.78 cu. ft. of digestion space per capita at 8,000 population. This unit has given more problems than all the other units combined. Leaks around the heat exchangers and the bed plate of the mixer were found to be due to two causes—faulty gaskets and poor concreting. Faulty gaskets were remedied by raising the plates and inserting another ring of the usual round rubber gasket material well-coated with aviation-type gasket cement. All bolts were wrapped with lamp wicking soaked with white lead. A large washer was then slipped over the bolt and the nut drawn down tight. In view of this experience it seems that the method of gasketing these parts would be greatly improved by the use of a flat rubber gasket about 1½ in. wide and ¼ in. thick, punched to slip over the bolts, similar to an automotive-type gasket.

After making sure the gaskets were tight, gas leakage was still observed. It was necessary to chip out quite a few places around the steel work where it was embedded in the concrete and seal these places with Water Plug and grout. Afterwards, a coating of Farbertite was applied and these places are now leakproof. However, soap tests showed the whole dome to be porous. Some of the larger holes were chipped out and sealed with Water Plug. The whole top was then coated with a roof sealer, followed by two coats of aluminum-colored roof coater.

Digestion is proceeding slowly but satisfactorily. However, because of the small daily increase of solids in the digester, no sludge has as yet been drawn. When this becomes necessary there are two sludge drying beds, 40 ft. by 90 ft., one covered and one open. Each is divided into four sections. Disposal of dried sludge will not present any problem. With 3.5 acres of lawn to be built and seeded, no sludge will be available to outside customers for at least a year. Nevertheless, several greenhouse operators and private gardeners have called regarding this material, and it is anticipated that enough demand may be created to derive a certain amount of revenue from its sale.

*Auxiliary Equipment*

The control building and the digester are heated by a hot-water generator located on the operating floor of the control building. This unit is fitted to burn either fuel oil or sludge gas, the controls being so arranged that the changeover from one fuel to the other is automatic. An integral water heater provides a generous supply of domestic hot water at all times. Also on the operating floor are the two gas meters and other gas controls.

All equipment on the operating floor and in the deep dry well can be easily removed for repair or overhaul by means of conveniently placed chain hoists hung from rollers on I-beams.

One change was made in location of equipment. The small plant water pump had been located on the operating floor, where it was subjected to dampness and splashing of water when the floor was washed. Also, the only valve on the supply line was near the chlorine contact tank. This condition was remedied by placing the pump on a small shelf about 30 in. above the floor and installing valves on the pump inlet and outlet connections. This makes it possible to remove the pump for repairs in a much shorter time and, by keeping it above the floor, prevents much moisture from entering the motor housing.

*Control Equipment*

The main control panel contains the main incoming powerline switch and breaker and the switch for the emer-

gency generator at one end. From here the current is divided to 14 other 440-v. switches and breakers, one for each motor on each piece of equipment. A small red light shows when each piece of equipment is in operation. There are also switches and breakers for the heating and lighting circuits and the 110-v. switches for the various lower-voltage units in the control building. Each motor is also equipped with a weatherproof, enclosed "off-on" switch within easy reach of anyone working on the equipment.

The raw sewage pump control is a float-actuated, mercury switch unit. On two different occasions, unusual conditions caused this unit not to function correctly. In the first instance, during turbulent flow in the wet well, the float got out of the float cage because of faulty design of the cage. This condition was remedied by covering the cage with woven wire fencing with a mesh size smaller than the float.

The other problem occurred when, during an extremely severe electrical storm, lightning struck through the unit, burning two tiny holes through the insulation covering the leads from the mercury switches to the terminal strip. These leads at times would come very close to the metal housing of the unit and a short would develop, cutting out the pumps. This was difficult to locate; before it was completely corrected, the dry well was flooded to a depth of 17 ft., causing much damage. After locating the trouble, the housing was lined with a piece of insulating fiber.

*Emergency Generator*

The emergency generator unit consists of a 4-cylinder, 77-hp. gasoline engine direct-connected to a 37.5-k.v.a. generator delivering 440-v., 3-phase, 60-cycle current to the main control panel. The treatment plant is close to an electric substation, but there have been instances of blackouts lasting for some time. The area is also a critical one from the standpoint of industrial power use. On two different occasions within a recent three-month period it has been necessary to operate this unit continuously for 8 hr. or more.

## Alarm System

The plant is equipped with an alarm system which is the only one of its kind known to the writer. Relays operating on low-voltage current are connected to each of the breakers controlling the important operating equipment, to the

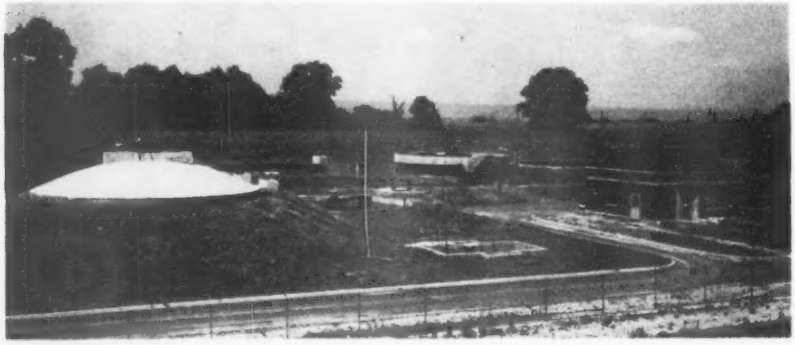

**FIGURE 2.—One-man two-stage high-rate filter plant depends on unusual leased-wire alarm system to notify of plant emergencies.**

high- and low-water alarm, to the main line switch, and to a 45° minimum temperature control mounted on the panel. The relays have switches and a light indicator mounted in the control building. The whole unit is connected by a leased telephone circuit to a light and buzzer in the central fire alarm control room in the Borough Hall, where someone is on continuous duty. The alarm system is in continuous operation; should anything occur to any piece of equipment during the absence of plant personnel, an alarm is immediately sounded in the central office. Three persons know what to do at the plant in case of emergency, and one of the three must be available at all times. The system cost about $325 to install and the rental of the connecting telephone lines is $5.50 per month; however, it saves the Borough the salaries of one or possibly two relief operators, and enables the regular operator to enjoy an almost unbroken week-end.

### Operating Results

Under present loads and operating conditions, settleable solids removal reaches an average of 99.9 per cent, such high removal being partly due to the long detention period. Suspended solids removed drop from 146 p.p.m. in the raw sewage to 30 p.p.m. in the primary clarifier effluent, and to 2.5 p.p.m. in the final effluent. Dissolved oxygen shows an increase from 3.5 p.p.m. in the primary clarifier effluent to 8.1 p.p.m. in the final effluent. A chlorine residual of 0.5 p.p.m. is carried in the final effluent.

The B.O.D. averages about 315 p.p.m. for the raw sewage and 10.9 p.p.m. for the effluent. B.O.D. reduction is consistently better than 95 per cent, with an average of 96.4 per cent. The rock filters are loaded at about 0.45 lb. of B.O.D. per cubic yard of rock. The plant was designed for a loading of about 1.1 lb. of B.O.D. per cubic yard of rock, exclusive of B.O.D. in the recirculated effluent.

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## OPERATION OF ACTIVATED SLUDGE PLANT AT MEADVILLE, PA.*

By Dewayne Day

*Superintendent of Sewage Treatment, Meadville, Pa.*

Meadville, Pa., is located in the northwestern part of the state about 10 mi. from Conneaut Lake, the largest natural lake in Pennsylvania, and about 40 mi. from Lake Erie. The two main industries are the Talon Fastener Company, maker of the hookless fastener, and an American Viscose Company rayon plant. As both of these plants treat their own industrial wastes, the Meadville sewage is essentially a domestic sewage, with the exception of some wastes from tool plants. At times, however, there is an indication of batch quantities of an organic cleaning solvent containing a considerable amount of oil being discharged to the sewers. The city, with a population of 20,000, is practically 100 per cent sewered.

The effluent from the sewage plant flows into French Creek, one of the fairly clean streams of Pennsylvania. One city below Meadville uses the creek for a public water supply, and it is used extensively for recreational purposes.

All sewage received at the plant is

* Presented at 1951 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1951.

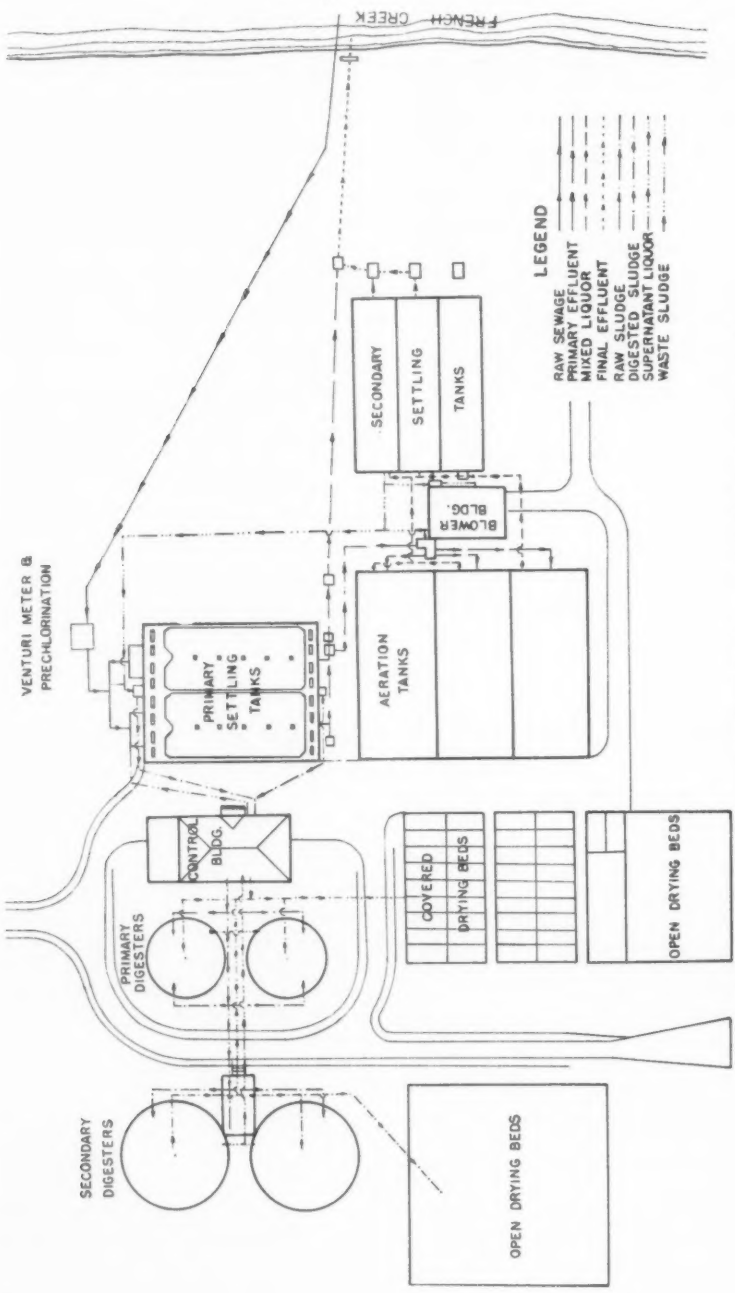


FIGURE 1.—Flow diagram of Meadville, Pa., activated sludge treatment plant.

pumped from a main pumping station through a 16-in. cast-iron main. A mechanically cleaned bar screen protects the pumps from rags and other debris, which are incinerated. The sewage is pumped by four vertical centrifugal pumps with motors installed 1 ft. above the maximum flood level. The rate of pumping is controlled by an automatic float control. The variation in the pumping rate is gradual, so that sewage flows are delivered to the plant at about the same rate that they are received at the pumping station. There are 13 variations between the minimum rate (1,000 g.p.m.) and the maximum rate (5,700 g.p.m.)

## Treatment Plant Units

### *Primary Settling*

The two rectangular primary settling tanks (Figure 1) have a total capacity of 312,000 gal. and are equipped with endless chain sludge collectors, the sludge being pumped from a sump near the center wall. Scum can be discharged from either end of the tanks to the digesters or to scum beds. The sludge mechanism is operated for about 1 hr. before pumping, which is done in the morning and sometimes during the afternoon, especially during the summer. The capacity of the primary settling tanks is much larger than presently needed. During the night, when flows are low, the detention period is greatly in excess of that desirable for an activated sludge plant. The single chlorinator is used for pre-chlorination to help prevent the sewage from becoming septic and to aid in controlling odors. The primary treatment, separate sludge digestion, sludge drying, and pre-chlorination units were completed in 1932.

### *Digestion*

The total capacity of the four digesters is 130,000 cu. ft., which represents 6.5 cu. ft. per capita. Two of the units, provided with floating covers, heating coils, and gas collecting equipment, are operated as primary digesters in a two-stage system; the two uncovered digesters serve as the secondaries. Sludge is pumped to each of the primaries daily. An effort is made to keep the alkalinity of the two primary digesters above 2,000 p.p.m. (equivalent as $CaCO_3$) and the temperature at 85° F. Lime or supernatant from the secondary digesters has been used to maintain this alkalinity. Both have

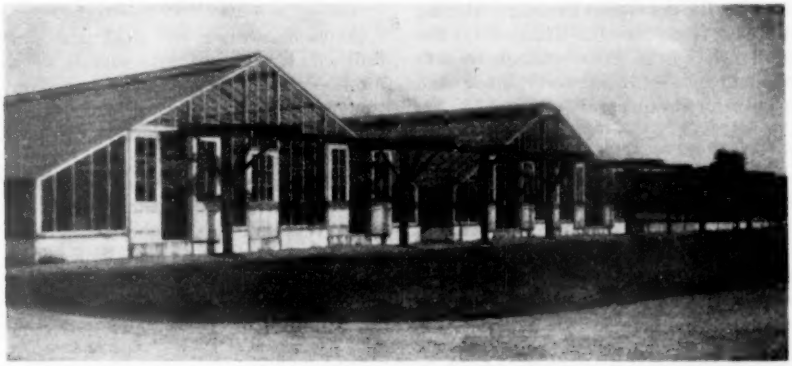

FIGURE 2.—Covered and open (right background) drying beds are served by overhead monorail carrier system for easy loading of trucks by farmers utilizing sludge for fertilizer.

FIGURE 3.—Blower building, aeration tanks (foreground), and final settling tanks (behind blower building).

been successful; but the supernatant from the secondary digesters proves to be more economical and, of course, introduces nothing foreign to the digestion system.

*Sludge Drying*

The plant has about 20,000 sq. ft. of underdrained sludge beds, with about 0.3 of the area covered (Figure 2). Sludge can be drawn from any of the four digesters. The dried sludge is given as fertilizer to farmers, who remove the sludge from the beds and furnish the trucks for hauling. During the last few years the demand for the sludge has been great enough to save the expense of using city labor and trucks for its disposal.

*Aeration and Final Tanks*

The secondary units (Figure 3), constructed from 1937 to 1943, include three aeration tanks, three final settling tanks, and a building to house two electrically-driven blowers and a third blower driven by a 45-hp., 3-cylinder sewage gas engine.

The three aeration tanks have a capacity of about 1 m.g. Each tank is provided with two passes, each pass having two rows of diffuser plates. This blower combination gives great flexibility in the amount of air used and may be varied from a low of 450 to a high of 3,000 cu. ft. per min.

Although three final settling tanks were constructed, the third tank has not yet been provided with sludge collecting mechanism. Total capacity of the two tanks in operation is 216,000 gal. Sludge is drawn by gravity from each tank to a wet well and returned to the aerators by pumping to a manhole where it is mixed with the incoming primary effluent.

## Operation

As each aeration and final tank was finished, it was put into service on a bio-flocculation basis. The primary effluent was aerated without return sludge and discharged through the final tanks to the creek.

Activated sludge treatment was started during the summer of 1944. Each year since, the plant has been operated on this basis for about seven months, returning to primary treatment during the winter months, when the condition of the receiving stream does not warrant such a high degree of treatment. During the first two years of operation laboratory control was very limited, consisting only of relative stabilities, suspended solids in the

mixed liquor, and an occasional check by the State Health Department. In 1946, samples were collected on the half hour and composited over a 14-hr. period beginning at 8 A.M. every other Wednesday. The samples were analyzed for B.O.D., suspended solids, and the other common routine checks made on sewage samples. During the summers of 1947 and 1948, sampling was increased to every Wednesday. The results of these one-day analyses were rather erratic, and plant performance failed to agree with expectations, resulting from the interpretations of the analyses. The results of this one-day-a-week sampling are invaluable as a matter of record, but proved the difficulty in attempting to operate an activated sludge plant on this limited control. Averages for these one-day-a-week analyses for three summers are as follows:

| | |
|---|---|
| Susp. sol. in mixed liq. (p.p.m.) | 1,450 |
| Sludge index | 120 |
| Over-all susp. sol. rem. (%) | 79.9 |
| Over-all B.O.D. rem. (%) | 88.8 |

In the summer of 1949, an effort was made to improve the efficiency of the plant by maintaining greater laboratory control and by subjecting more primary effluent to secondary treatment without increasing the cost of the air consumption. This control reflected itself in much better suspended solids removal and a slight increase in B.O.D. removal. The average B.O.D. of the final effluent was 15 p.p.m.; suspended solids averaged 7 p.p.m. The effluent samples were taken by an automatic sampling device, which composited equal portions of sample over a 24-hr. period. Samples were analyzed Monday through Friday.

In spite of the excellent results obtained, the activated sludge was in a bulky state most of the summer, the average sludge index of 331 indicating the poor settling quality of the sludge. The high sludge index was attributed to the increased rate of flow through the aeration tanks, which decreased the period of aeration. To maintain aerobic conditions, the suspended solids in the mixed liquor were reduced to an average of 907 p.p.m. In comparing the 1949 results with the average results of the previous three summers, there is an indication that the sludge with a high index will give improved suspended solids removal and just as good or better B.O.D. removals as a sludge with a low index. However, a high index does not give the operator the feeling of security and confidence that is obtained when the plant is being operated with sludge having a low index, and sludge with a high index is much more sensitive to an upset.

During the summer of 1950, chlorine was used in the return sludge in an attempt to lower the high index experienced the summer before. This method of control has been described by Tapleshay (1). The effect of the chlorine was aptly demonstrated by a drop in sludge index from 378 to 100 in a 10-day period. The experiment was continued for about a month and a half with intermittent periods of chlorination. Each time the index would drop while chlorine was used and would increase when chlorination was stopped. The objection to this method of control was that it required use of the only chlorinator, needed for prechlorination, and resulted in the appearance of an oily-looking scum on the surface of the final tanks. The grease content of the return sludge was about 19 per cent on a dry solids basis, and the action of the chlorine and air was probably responsible for causing it to float on the final tanks. Operation data for the summer months are given in Table I.

The critical stage of the plant centers around the aeration and final tanks. Priority of future improvements will be given to them. Money has been appropriated for the sludge collecting mechanism for the third final settling tank. This added unit should increase the plant's over-all efficiency. Installation of a pump to return final effluent to the primary tank inlet at

**TABLE I.—Summary of Operation Data for Meadville, Pa., Sewage Treatment Plant**

| Determination | Period | | | | |
|---|---|---|---|---|---|
| | June 26–Sept. 18, 1946[1] | June 18–Oct. 1, 1947[2] | July 14–Sept. 8, 1948[2] | June 11–Sept. 17, 1949[3] | June 11–Sept. 9, 1950[3] |
| pH: | | | | | |
| Raw | 7.20 | 6.95 | 7.15 | 7.20 | 7.30 |
| Settled | 7.35 | 7.05 | 7.25 | 7.20 | 7.30 |
| Final | 7.45 | 7.22 | 7.35 | 7.70 | 7.40 |
| Alkalinity (p.p.m. as $CaCO_3$): | | | | | |
| Raw | 290 | 248 | 284 | 277 | — |
| Settled | 273 | 236 | 274 | 262 | — |
| Final | 185 | 166 | 174 | 208 | — |
| Acidity (p.p.m. as $CaCO_3$): | | | | | |
| Raw | 39 | 35 | 33 | — | — |
| Settled | 27 | 26 | 26 | — | — |
| Final | 16 | 12 | 12 | — | — |
| Settleable solids (ml./l.): | | | | | |
| Raw | 5.3 | 5.5 | 4.8 | 5.0 | 6.2 |
| Settled | 0.04 | 0.15 | 0.2 | 0.5 | 0.3 |
| Rem. by primaries (%) | 99.3 | 97.1 | 95.8 | 90 | 95.2 |
| Total solids (p.p.m.): | | | | | |
| Raw | 740 | 735 | 840 | 794 | 815 |
| Settled | 607 | 565 | 694 | 647 | 664 |
| Final | 531 | 510 | 603 | 675 | 541 |
| Over-all red. (%) | 28.2 | 30.6 | 28.2 | 15.0 | 33.6 |
| Total susp. solids (p.p.m.): | | | | | |
| Raw | 273 | 261 | 285 | 210 | 211 |
| Settled | 114 | 113 | 149 | 77 | 73 |
| Final | 66 | 53 | 45 | 7 | 9 |
| Over-all red. (%) | 75.8 | 79.6 | 84.4 | 96.6 | 95.8 |
| 5-Day B.O.D. (p.p.m.): | | | | | |
| Raw | 273 | 242 | 246 | 186 | 173 |
| Settled | 118 | 124 | 126 | 103 | 102 |
| Final | 28 | 28 | 28 | 15 | 19 |
| Over-all red. (%) | 89.7 | 88.4 | 88.5 | 92.0 | 89.0 |
| Return sludge: | | | | | |
| M.g.d. | 0.87 | 0.90 | 0.90 | 0.96 | 0.97 |
| Solids, by volume (%) | 28 | 47 | 71 | 65 | 44 |
| Solids, by weight (%) | 0.36 | 0.39 | 0.59 | 0.27 | 0.25 |
| Volatile solids (%) | 77 | 77 | 76 | 72.1 | 73.3 |
| Return ratio (%) | 46.0 | 40.2 | 42.0 | 41.2 | 41.5 |
| Prim. effl. aerated (m.g.d.) | 1.89 | 2.24 | 2.14 | 2.31 | 2.34 |
| Mixed liquor: | | | | | |
| Solids, by volume (%) | 17 | 15 | 20 | 30 | 15 |
| Wt. of solids (p.p.m.) | 1,300 | 1,300 | 1,750 | 907 | 768 |
| Volatile solids (%) | — | — | — | 81.2 | 77.6 |
| Sludge index | 131 | 115 | 114 | 331 | 195 |
| Air: | | | | | |
| Million cu. ft./day | 2.02 | 2.08 | 2.11 | 2.11 | 2.22 |
| Cu. ft./gal. | 0.93 | 0.92 | 0.95 | 0.91 | 0.94 |
| Cu. ft./lb. B.O.D. to aer. | 1,085 | 900 | 940 | 1,055 | 1,110 |
| Lb. B.O.D. to aerators | 1,860 | 2,310 | 2,250 | 2,000 | 1,990 |

[1] Average of 1-day analyses taken on alternate Wednesdays. Uniform samples of raw and settled sewage taken every 30 min. and composited over a 14-hr. period. Final sample taken by automatic device; uniform portions composited over 24-hr. period.

[2] Average of 1-day analyses taken each Wednesday. Method of sampling same as for 1946.

[3] Average of 5-day per week analyses. Uniform raw and settled samples taken hourly and composited over 12-hr. period. Method of taking final sample same as for 1946.

night when the sewage flow is so low would decrease the detention period, making possible the flow of a fresher sewage to the aerators. It would also eliminate the need for pre-chlorination, making the one chlorinator available for post-chlorination. This would also aid in increasing over-all efficiency.

The future emphasis of routine laboratory control will be placed on the secondary process. It is realized that it is extravagant to use more air than is necessary, but it is folly to attempt to operate unless aerobic conditions are maintained in the aerators and final tanks at all times. In the past, a constant rate of 1,500 c.f.m. of air has been used and the solids in the mixed liquor have been varied to maintain an excess of oxygen. However, in a recent prolonged dry spell, which increased the volatile matter in the mixed liquor, the air consumption had to be increased to 1,750 cu. ft. per min. during the day to maintain aerobic conditions in the final tanks.

Settled activated sludge from the final settling tanks is returned to the aerators just as rapidly as possible at all times. This rate is about 40 per cent of the primary effluent treated. Excess sludge is wasted slowly over a 24-hr. period to the inlet of the primary tanks. Supernatant liquor from the digesters is discharged to sand beds during the period when the activated sludge process is being operated.

The plant is staffed by two full-time operators, a part-time man three months of the year for the upkeep of the grounds, and the writer.

The gas engine is operated during the day from 8 A.M. to 8 P.M. The plant is operated on electric power during the night with no attendant present.

The present operation of the plant is hampered because of insufficient past laboratory control data. It is hoped that by increasing the laboratory control, it will be possible by intelligent trial and error methods to determine the proper amount of mixed liquor solids and air necessary to assure the type of effluent required by the receiving stream.

### Reference

1. Tapleshay, J. A., "Control of Sludge Index by Control of Return Sludge." *Sewage Works Jour.*, **17**, 6, 1210 (Nov., 1945).

## TIPS AND QUIPS

### Selective Insecticide

A new systemic insecticide, Isopestox, claimed to be selective to the extent that it kills only bad bugs, is glowingly described in an article in the July, 1951, issue of *Chemical Engineering*. Non-volatile, odorless, and non-corrosive, the chemical is available as a 50 per cent anhydrous solution containing a warning color, methyl violet.

The article states that with development of Isopestox, which is applied as a spray in concentrations between 0.05 and 0.1 per cent, pest control has taken a great forward step toward its aims for systemics—to kill pests which could not be killed before; to produce further selective methods of application; and to produce systematic insecticides less toxic to man. When Isopestox is applied to the roots of a plant, the sap stream will carry it to the feeding places of damaging insects. Oral toxicity is low and the insecticide can only exist in the plant's system for one to two weeks.

The composition of the chemical? Simple bis-isopropylaminofluorophosphine oxide.

### Ice Remover

Ice-Rem, ice and snow melting compound whose thawing capacity is claimed to be 30 times that of salt or 10 times as quick-acting as standard

flake calcium chloride, is available in 10-lb. and 25-lb. pails, 100-lb. drums, and waterproof 100-lb. bags. Besides the obvious uses in clearing snowy and icy roads, steps, and walks, the chemical is recommended for thawing frozen gutter pipes, sewers, and railway switches. Speco, Inc., 7308 Associate Ave., Cleveland 9, Ohio, is the manufacturer.

### Electrical Tape

A new heavy-duty plastic electrical tape with high mechanical strength has been announced by Minnesota Mining and Manufacturing Co., St. Paul, Minn. Available in 36-yd. rolls in widths from ¼ in. to 16 in., "Scotch" brand electrical tape No. 21 is recommended by the manufacturer for anti-corrosion protection for pipes, cables, and equipment laid underground where resistance to cuts and abrasion by rocks during backfill is important. It is also recommended for protecting and insulating cable and high-tension leads subject to wear, abrasion, and rough handling, and for bus bars carrying high voltage.

The tape has a black vinyl plastic backing that is 20 mils thick, a dielectric strength of 22,500 v., an insulation resistance of 200,000 megohms, and an electrolytic corrosion factor of 1.0.

### Unprovoked Attack

In a paper presented at the 1951 Fall Meeting, New England Sewage Works Assn., held at Providence, R. I., Nov. 6–7, 1951, some of the problems encountered during the first year of operation of the new Warren, R. I., sewage treatment plant were discussed by James W. Crowley, superintendent.

Among the more unusual items mentioned was the overloading of the new plant's grit chamber by fine grit and quahog meats from a quahog-opening plant supplying meats for out-of-state clam chowder canneries. This particular problem was easily solved by calling attention to the considerable loss of additional profits represented by the meats and persuading the industry to screen them out and construct its own discharge line to the adjacent river for grit disposal.

However, the clams continue to reach the plant—not as unshelled meats, but as hard-shelled, damaging missiles. It seems that the sea gulls, which feed off the nearby quahog piles, often miss the intended target area on hard roads and sidewalks when they drop the shellfish to open them, with disastrous effect on the glass of the covered sludge drying beds!

### Safety Comes First

Under the headline "Safety Comes First at City Disposal Plant," Leo Holtkamp, superintendent, Webster City, Iowa, sewage treatment plant, was recently lauded by the *Webster City Graphic* for his safety practices. In an excellent newsy and informative half-page article, the local public was informed of the hazards involved in the operation of the plant and the methods used for overcoming and avoiding them. Some pertinent personal data on Mr. Holtkamp's background and experience were effectively woven into the story.

Such items in the local newspapers are excellent builders of good public relations for any plant. The point to be made, however, is that the superintendent has been made a personality in the minds of the public, not treated as another piece of machinery in the plant. Also, the stress on the safety angle leaves the distinct impression that the city might well feel proud of the manner in which a large but necessary capital improvement is being operated and maintained.

**Hunt scrap—Collect scrap—Save scrap—Sell scrap!**

# Reviews and Abstracts*

**Sewerage and Sewage Treatment in the Future: A Preview.** By W. Fillingham Brown. *Surveyor*, **110**, 39 (Jan. 19, 1951).

As long as the problems of sewage treatment remain the same, no fundamental changes are anticipated in the principles of their solution. Removal of solids is presently best accomplished by sedimentation, and the most likely advances are improvements in sedimentation efficiency. With high flows, fine screening may in some cases prove more economical than sedimentation. The oxidation of dissolved and colloidal impurities is achieved by natural biochemical means. It is unlikely that this process will ever be rivaled in cost or efficiency by purely chemical means. Advance is most likely along the lines of further intensification of biochemical processes. However, certain physical factors place definite limits on such intensification.

Disposal of sewage sludge presents the greatest possibilities for improvement. The most important problem is that of dewatering. Return of sewage sludge to the soil is desirable, but requires better dewatering than is now available, to make it feasible on a large scale. Heat drying is essential, either at low temperatures generated by bacterial action, or at high temperatures generated by combustion of fuel. Utilization of waste heat from other processes is a possibility, as is heat production by burning sludge gas and, perhaps, dried sludge. The methane of sludge gas may serve as a raw material for organic syntheses.

The keynote of future developments is increased efficiency in existing processes, and greater emphasis on utilization, rather than mere disposal.

On the administrative side, regionalization is expected to replace small local treatment plants.

Industrial wastes present an ever-increasing problem. That of radioactive wastes is particularly difficult.

M. C. Rand

**Cleaning of Porous Air Diffusers.** By A. Bruce and R. J. Stephenson. *Surveyor*, **110**, 51 (Jan. 26, 1951).

The principal causes of clogging of the air diffusers in activated sludge plants are:

1. Activated sludge solids forced into the plates when the air pressure in the supply pipes falls or is interrupted.
2. Iron rust on the underside of the plates, from the rusting of air supply pipes.
3. Hard-water scale.
4. Gelatinous growth of organisms on the top surface.
5. Grease accumulation on the top of the plates.
6. Coal dust and soot from the atmosphere.

Plates were cleaned by treating them overnight with 30 per cent caustic soda, followed after rinsing by 1-hr. exposure to 1:1 hydrochloric acid. Cleaning was accomplished without removing the diffuser plates from the iron trays in which they were mounted. The trays were removed from the aeration channels and each tray, and the plates in it, was treated as a unit. The wet-test porosity of the chemically cleaned plates approached closely that of new plates. The cost of chemical cleaning was less than one-fourth that of cleaning by firing, even without considering breakage. Rubber gaskets, wax washers, brass screws and the iron trays were not injured by the chemical cleaning process.

M. C. Rand

**Sewerage and Sewage Disposal in 1950.** Anon. *Surveyor*, **110**, 89 and 105 (Feb. 16 and 23, 1951).

The general condition of sewerage and sewage disposal (in England) showed little

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

or no improvement during the year. Expenditures for sewerage and disposal facilities have been so severely restricted as to make it difficult if not impossible to counterbalance the aging of plants and equipment, the increase of population, and industrial expansion.

Research in sewage disposal presents a better picture. A variety of problems were attacked, including biological filtration of sewage, control of filter flies, removal of solids from effluents by mechanical filtration, effects of treatment processes on the types and number of bacteria in sewage, development of methods for determining the toxicity of different substances to fish, effects of detergents, and enclosed filters. These projects were handled by the Water Pollution Research Board, by municipalities, and by industries. A new edition of "Standard Methods" is in preparation by the Ministry of Health.

It is recognized that the relationship between sewage disposal and water supply is becoming steadily closer. Treated effluents often are discharged into streams whose lower reaches must serve as a source of potable water. In such cases the division of responsibility for purification is a delicate question. Rather than establishing a fixed precedent, it is preferable to decide each case on its own merits.

Experimentation, described in detail elsewhere, is reviewed. The work on high-rate filtration, deep enclosed filters, dewatering of sludge by freezing and composting, and the effects of synthetic detergents receive particular attention.

M. C. RAND

**National Water Policy.** Engineers Joint Council Committee Report. *Jour.*, Am. Water Works Assn., **43**, 1, 24 (Jan., 1951).

This article is an excerpt of the report on "Domestic and Industrial Water Supply and Pollution" that was prepared by Task Force No. 1 of the Engineers Joint Council for the President's Water Resources Policy Commission. A part of the report was also published in THIS JOURNAL, **23**, 2, 210 (Feb. 1951).

The report first states that the use of water resources for domestic and industrial purposes is believed to be the highest and best use, as without adequate water supply properly safeguarded against pollution urban life cannot exist. Current shortages of water in certain areas are attributed to concentrations of population and industry without due regard to the available supply, as the over-all national availability of water is more than adequate.

Control of water wastage and the value of flood control are cited as means for conserving and making better use of existing supplies. Emphasis is also placed on the need for substitution of salt water for fresh water, when industry is located on coastal areas. The need for enforceable legislation relating to the conservation of underground waters is another point that is strongly urged.

In order to provide water for our expanding industries, a corrective program should include:

1. An inventory of water requirements on a national basis coordinated with actual and potential water resources available, including both surface and ground waters. This survey should be both local and areawise with respect to major river basins and geological formations.

2. Making available factual data regarding overindustrialization within critical, or potentially critical, water areas and the desirability of decentralization of industrial users of large volumes of water.

3. A study of the inter- and intra-state control and regulation of flood waters to provide present and future industrial water requirements, regardless of other benefits accruing from such facilities.

4. Publication of salt-water usage as a conservation measure.

5. Expanding the activities of the state and federal agencies handling critical underground water resources problems.

6. Providing technical personnel for the U. S. Geological Survey and comparable state organizations, together with the necessary funds to effect more adequate utilization of the valuable services of these organizations.

7. Coordinating the activity of waste disposal regulation groups with those interested in resources.

ROBERT P. LOWE

**Pollution Control and Property Rights.** BY JOHN H. MURDOCH, JR. *Jour.*, Am. Water Works Assn., **43**, 1, 61 (Jan. 1951).

This interesting presentation of a hypothetical, but typical, stream pollution

problem is made by a lawyer who has evidently had prior experiences with such cases.

The presentation brings out the complications that can result to public water supplies from the combined effects of wastes from additional acid mine drainage, from a rayon plant, a chemical plant, an oil refinery, and from oil well brines. To add to the confusion, it is pointed out that in all probability no single industry in itself would make the public water supplies unsatisfactory for treatment to give a potable water.

The legal remedy is summed up in the essential fact that the health and safety of the public are endangered because of the pollution of the source of water supply. The industries and communities, in this case, by the complicated interplay of their various activities, have endangered the public health and safety. Acting as individuals but within a common framework of circumstances, each has contributed to this final result. The result is an offense against the state, an inconvenience and danger which annoys and threatens the whole community and not merely some particular person. It is a public nuisance, which may be abated at the instance of the state without the payment of any compensation to those whose actions are regulated. No one can have a property right to commit or maintain a public nuisance, and the state can be required to pay compensation only when property rights are taken away.

In summarizing this hypothetical case, it is stated that the state, through the exercise of its police power, can prohibit pollution without paying any damages. It is up to the legislative branch of the government to fix the standards and limits of permissible pollution, and such limits will be upheld by the courts, unless they are clearly unreasonable. Therefore, it is evident from this presentation that if waterworks officials are alert and have courage, the law will help in stream pollution control. ROBERT P. LOWE

**Evaluation of Stream Pollution.** BY L. L. HEDGEPETH. *Jour.*, Am. Water Works Assn., **43**, 1, 55 (Jan., 1951).

A representative of industry presents his viewpoints in this paper on the stream pollution control program. Due to the extensive costs involved for treatment plant construction and maintenance, the author insists that nothing short of absolute legal requirements will get the job done.

Much of this paper covers the opposition to standards for treatment. This is based on the lack of a proper yardstick for measurement of industrial pollution and on the variable effect of industrial wastes on a stream. For measurements of pollution the merits and weaknesses of the biochemical oxygen demand, the new bioassay techniques, and chemical and physical tests, are discussed. In contrast, it is stated that no one test is applicable and that considerable specific experience and mental alertness are needed to judge each situation on its own merits. In other words, critical appraisal of stream pollution is deemed to be desirable instead of using general criteria for all situations.

In conclusion, the progress made by industry to date is cited. Much more has been accomplished than appears on the record, as many leading industries have accepted waste treatment as a necessary part of new plants or expansions. Technical men in industry are also using their special skills and process knowledge to solve the varied problems of industrial pollution, and this information is being freely exchanged at heavily attended and unpublicized conferences of industry.

ROBERT P. LOWE

**The River Boards Act, 1948, and Its Implications.** BY J. V. MORLEY. *Surveyor*, **110**, 123 (Mar. 2, 1951).

Great Britain's River Boards Act, 1948, in brief, enables the Minister of Agriculture and the Minister of Health, acting jointly, to constitute River Boards, which are taking over the powers of:

1. Catchment Boards, formerly constituted under the Land Drainage Act, 1930, whose duty was to look after land drainage and flood alleviation.
2. Fishery Boards, whose duty in the main was to look after fisheries and which also had certain powers relating to pollution.
3. The pollution powers formerly vested in local sanitary authorities.
4. Certain other responsibilities on gaging of river flows, which belonged to no one in particular in the past.

Prior to 1930, land drainage and stream pollution were administered under a confusion of piecemeal legislation, which had accumulated over nearly 500 years. The

Land Drainage Act of 1930 was a milestone in land drainage law, but the Catchment Boards which it established operated under severe difficulties arising from the financial crisis of the 1930's and the war of the 1940's.

The new River Boards do not yet have adequate powers for dealing with pollution, but will have the advantage of being large enough to have competent staffs and be able to call upon the best expert advice. Also, each river and its tributaries will be treated as a whole and come under the jurisdiction of a single authority.

The River Boards can only expect to progress slowly towards their ultimate objectives in pollution abatement. But with patience, it is anticipated that much will be accomplished eventually.

M. C. RAND

**A Main Drainage System Below Sea Level.** By T. COATES AND D. R. SHARP. *Surveyor*, **110**, 139 (Mar. 9, 1951).

The paper describes some aspects of the planning, design, and construction of the new main drainage system being carried out at Kingston-upon-Hull. The difficulties confronting an urban authority so placed that 88 per cent of its present area is below mean high water of spring tides are dealt with, and the paper concludes with a description of a new pumping station now under construction in West Hull, which is founded 60 ft. below ground level.

M. C. RAND

**A Critical Approach to Sewage Works Design.** By B. F. P. BABCOCK. *Surveyor*, **110**, 141 (Mar. 9, 1951).

The paper questions certain practices in sewage works design, which, the author feels, are dictated more by "tradition" than by more practical considerations. There are also some suggestions for future research, and some predictions of future developments.

It is suggested that lighter pattern sluice valves, perhaps of the type used in gasworks, might profitably replace the waterworks pattern commonly specified. A good quality screw-operated penstock of proper design might be preferable to the sluice valve usually attached to a sludge outlet. Asbestos cement sheet is an alternative material to metal or wood for scum boards and baffles. Penstocks which are used solely for controlling flow rates, and which are rarely, if ever, shut off completely, need not be drop-tight when closed. Improvements are suggested for the method of fixing ironwork to brick or concrete walls, for passing pipelines through the walls of structures, and for the general design of buildings.

Research is needed on the hydraulics of flow through a complete treatment plant; on quick, qualitative tests of effluent quality, for use in operating control; and on *in situ* tests for the strength of concrete.

The future developments predicted are mechanical removal of sludge from drying beds, more economical use of sludge gas for heat and power production, and an improved system of aeration for the activated sludge process, embodying the better features of the various existing systems.

M. C. RAND

**Drainage Considerations in the Development of a New Town.** By JOHN W. HENDERSON. *Surveyor*, **110**, 145 (Mar. 9, 1951).

Drainage considerations influence the planning and land use proposals of a new town, influence the economics of the development, control the expeditious start of development, and govern the rate of development. The author gives a rather comprehensive discussion of the factors to be considered in designing a drainage system, which include, as the most important among others: (1) any existing watercourses, and the extent to which they can accept sewage, storm water, or both; (2) whether a sewage disposal outfall exists, and if so, its capacity; (3) whether pollution of water courses is permissible; (4) the area of the proposed development; (5) topography and natural drainage areas; (6) the extent to which drainage from outside the designated area may influence proposals within the designated area; (7) geological information pertaining to the economics of excavation, and to the possibility of underground disposal; and (8) the extent and capacity of existing drainage systems in the area.

Many details are presented pertinent to estimating the required capacity of the system, and specifications for certain parts of the system are suggested.

The impact of drainage considerations upon land use planning and upon construction schedules is discussed at some length.

M. C. RAND

**Drains and Sewers—The Legal Aspect.** By L. Mair. *Surveyor*, 110, 157 (Mar. 16, 1951).

The author describes the complicated situation which exists in England with regard to the responsibility for cleaning and maintaining sewers and drains. To summarize very briefly, there is no clear-cut legal precedent for assigning such responsibility, especially where the pipes in question underlie private property.

It is suggested that the existing legislation might be improved, and the situation clarified, by making all cleaning and maintenance the responsibility of the local authority, and giving the local authorities the right to recover expenses so incurred when the sewers serviced lie under the premises which they serve.

M. C . Rand

**Modern Developments in Plumbing and Drainage.** Works Ministry Committee's Recommendations. *Surveyor*, 110, 189 (Mar. 30, 1951).

The conclusions reached by the Committee may be summarized as follows:

1. Before contractors' bids are invited, plumbing and drainage should be completely designed by qualified specialists.

2. Local authorities and water purveyors should be sure their requirements do not prevent use of any sound modern developments.

3. Inspection and approval of plumbing and drainage should be accomplished during installation. Examinations should be revised so that officers entrusted with inspection possess the necessary specialized knowledge of plumbing and drainage.

4. For water supplies, use of cold-water cisterns only to supply hot-water tanks, and connection of all other outlets to the mains, should be considered in all new work.

5. More attention should be paid to close grouping of appliances and simplification of the plumbing system.

6. The one-pipe system of soil and waste disposal should be more widely adopted.

7. There is considerable scope for effecting economies in underground drainage by using only the most suitable pipe sizes, reducing the number of manholes to a minimum, elimination of intercepting traps from connection to new sewer systems, and avoiding excessive use of concrete under and around pipes.

8. Prefabrication of parts of plumbing systems at the site should be adopted where practicable.

9. There is need of publicity for up-to-date developments; the knowledge is available, but its distribution is insufficiently wide.

M. C. Rand

**A Visit to United States Sewage Purification Plants.** By M. R. Vincent Daviss. *Surveyor*, 110, 215 (Apr. 13, 1951).

The author's outstanding impressions were the operation galleries at most of the large aeration plants, which, he feels, must be much appreciated by the operators; the provision of pipe subways for housing mains and services; and the enormous flow treated at many of the plants.

In some directions, the Americans have developed new ideas, while older practices have persisted in England. The outstanding example is in sludge treatment. In England, air drying is the usual practice, whereas in the United States limitations of available land have encouraged more compact systems such as vacuum filtration.

Rectangular settling tanks are used more in the United States than in England, and the endless flight scrapers commonly in use here are seldom if ever used in England.

The use of Imhoff tanks in America is declining.

The chain-type rakes, still commonly in use in the United States, are being replaced in England by those having no submerged moving parts.

M. C. Rand

**Disposal of Sewage from Small Rural Communities.** By Thomas G. Faulkner. *Surveyor*, 110, 221 (Apr. 13, 1951).

The design of small works, with dry weather flows from 10,000 g.p.d. downward, must receive very careful consideration. A sound and efficient scheme must be produced at minimum cost, which will probably mean the elimination of many desirable, but not definitely essential, features.

The engineer, in addition to keeping the capital costs at the minimum, must also remember that in very few cases is constant supervision of the works possible. The works may, in fact, have to be left unattended, or even neglected over very long periods.

The most generally suitable scheme for small treatment works is tank treatment followed by filtration. Because constant, or even regular, attention to the plant is not often possible, a septic tank is most satisfactory for the first stage of treatment. The author has found that a 24-hr. detention period is the best basis for design. The filters are usually 6 ft. in depth and, owing to the nature of the tank effluent, the designed capacity is a little on the generous side (around 35 g.p.d. per cu. yd.) The media are graded in layers from 3 in. to 1 in. The automatic tipper is used on small filters serving up to 10 houses, and rotary distributors on the larger filters.

Owing to the amount of attention required by humus tanks, it is advisable to dispense with these wherever possible, and to run the filter effluent over land prior to final discharge. Usually 15 to 60 yd. over land is sufficient. Where limited space makes humus tanks necessary, they must receive fairly regular attention. Sludge may be disposed of by burying.

**Discussion.** *Surveyor,* **110, 541** (Aug. 31, 1951).

In introducing the paper, the author stated that dip pipes were used as outlets for the septic tanks recommended as the first stage of treatment for plants of this type. Weirs are theoretically more efficient, but are more costly to construct. The flow through dip pipes is not sufficient to cause any great disturbance in tanks.

In general, the discussers agreed that the most satisfactory system for very small works is a septic tank followed by a trickling filter. It was pointed out that the tank had to be designed on the basis of sludge storage, and should accommodate twice the volume of sludge expected to accumulate between times of desludging. In reply, however, the author mentioned that considerable reduction of sludge occurs during storage, so that sludge may not accumulate to the extent anticipated if the period between desludgings is long. It was also stated that the design should provide for emptying the tank completely for desludging.

If the plant site makes pumping unavoidable, it is preferable to pump tank effluent rather than raw sewage because the former permits use of smaller, less expensive pumps.

It had often been said that the capacity of a very small trickling filter needed to be greater than the Royal Commission's general recommendation of ¾ cu. yd. per capita. However, in the experience of the various discussers, the recommended capacity gave satisfactory effluents.

There were several comments on the desirability of small rural treatment works in preference to cesspools.

It was generally agreed that running the filter effluent over land was preferable to providing a humus tank, whenever conditions permit.

One discusser described an experimental project wherein various types of septic tanks were tested. The conclusions were that the various types were similar in performance, and that 24-hr. retention was an adequate basis for design.

M. C. RAND

**Further Mechanical Developments in Rectangular Tank Desludging.** By H. D. THATCHER AND R. W. LUCAS. *Surveyor,* **110,** 317 (May 26, 1951).

In a previous paper presented in 1940, the authors showed that the results from a good rectangular tank were no worse than from a good circular one, and that the operating costs favored the former design. This paper describes developments which simplify the operation of rectangular tanks and enable existing rectangular tanks of good design to be modernized by installing mechanical desludging facilities.

The improvements described consist of the following items: the retractable undercarriage for transferring scraper mechanisms; the vertically-operated sweep; improved systems for automatic control of desludging apparatus; the "sludge concentrator," which is a laterally operated scraper for bringing the sludge to the outlet after it has been moved to the end of the tank; the system of installing a separate scraper for each tank rather than transferring one mechanism from tank to tank; and the redesign of the scraping mechanism so that the control cabin is at one side, rather than in the center, of the beam.

It is shown that operating costs of rectangular tanks using the improved system are significantly less than those of circular tanks, particularly with regard to the operators' time required for the desludging process.

M. C. RAND

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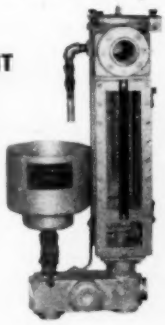

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# Proceedings of Member Associations

## SOUTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

The 17th Annual Meeting of the South Dakota Water and Sewage Works Conference was held at Yankton, S. D., September 19–21, 1951. The total number registered was 102.

The technical sessions opened the morning of September 30, the first half day being devoted to a general session with discussions on "Shot-crete and Its Use in Water and Sewage Works," by F. A. Esrup, followed by a discussion on "Rain Increasing," by Kenneth Raetz. The afternoon session of the sewage section heard papers as follows:

"Chlorination of Sewage," by Robert C. Goplin, Wallace & Tiernan, Minneapolis, Minn.

"The Cooperative State-Federal Pollution Control Program," by Leonard B. Dworsky, chief, Reports and Statistics Branch, Division of Water Pollution Control, U.S.P.H.S., Washington, D. C.

"Waste Segregation and Treatment," by C. J. Edwards, district manager, U & I Sugar Company, Belle Fourche, S. D.

"Operators' Discussion Period."

On Friday morning, September 21, the meeting again convened in a general session with discussions on "The Peoples' Stake in Water Pollution Abatement" by Mr. Dworsky; "The Yankton Water Treatment Plant" by John R. Sperry; and an inspection trip to the new municipal water plant.

The Federation's Bedell Award was made to Leland Bradney, chemist, Sioux Falls sewage treatment plant. At the banquet, on September 20, William Hahn, president, South Dakota Division, Izaak Walton League of America, announced that the Division would hereafter make an annual award of a plaque to a sewage treatment plant operator in South Dakota showing marked improvement of the plant or receiving watercourse

Officers elected for 1951–52 were:

*President:* W. Johnson, Huron.
*Vice-President:* A. Hanson, Sioux Falls.
*Secretary-Treasurer:* C. E. Carl, Pierre.

CHARLES E. CARL,
*Secretary-Treasurer*

## ROCKY MOUNTAIN SEWAGE WORKS ASSOCIATION

The 1951 Annual Meeting of the Rocky Mountain Sewage Works Association was held in conjunction with that of the Rocky Mountain Section, American Water Works Association, at the Cosmopolitan Hotel, Denver, Colo., September 24–26, 1951. Registration at the meeting totalled 52.

The program on September 24 and the entire morning of September 25 was devoted to waterworks topics.

At the afternoon session on September 25, papers of general interest to both groups were presented as follows:

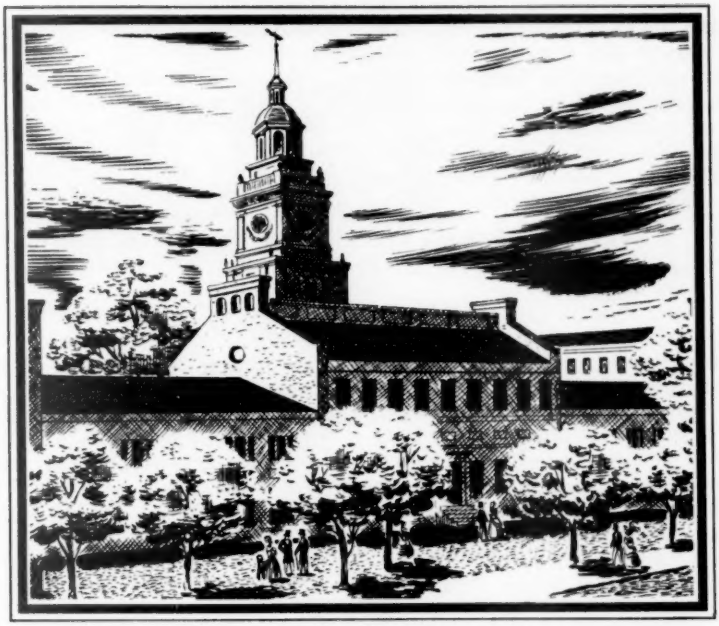
"Biological Warfare," by John Richty, associate professor, Colorado Medical School, Denver.

"Civilian Defense Relating to Water and Sewage Facilities," by Terry Owens, city engineer, Denver.

"Survival Under Atomic Attacks," by Henry A. Larson, director, Colorado Civilian Defense Agency, Denver.

A joint banquet-entertainment of the two associations was held the evening of September 25.

(*Continued on page 70a*)



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The technical sessions on September 26 opened with a motion picture on "Sewage Treatment," followed by a discussion period on treatment problems under the direction of Lloyd Leslie, assistant sanitary engineer, U.S.P.H.S., Denver. Papers were then presented as follows:

"Progress on Stream Pollution Control," by H. W. Poston, assistant basin engineer, U.S.P.H.S.

"Water Pollution Control Is Our Job," by W. N. Gahr, director, Division of Sanitation, Colorado State Department of Public Health.

"How to Obtain Critical Materials," by Charles E. Brokaw, regional director, U. S. Dept. of Commerce, Denver.

"Negative Pressures and Resulting Contamination," by Sam Kotz, public health engineer, Colorado State Department of Public Health.

"Progress on Sugar Beet Waste Treatment," by D. J. Roach, vice president, Great Western Sugar Co., Denver.

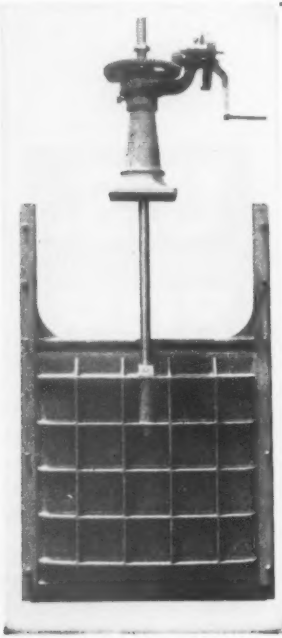
"Sanitary Districts," by Emory L. O'Connell, attorney, Denver, and Carroll H. Coberly, consulting engineer, Denver.

The meeting closed with a round table discussion on "Operation of Sewage Treatment Plants," led by Dana E. Kepner, manufacturers' representative, Denver.

Officers elected to serve during 1951–52 were:

*President:* R. Sherrard, Cheyenne, Wyo.
*Vice-President:* C. Coberly, Denver, Colo.
*FSIWA Director:* C. Caldwell, Santa Fe, N. Mex.
*Secretary-Treasurer:* C. E. Harness, Denver, Colo.

C. E. Harness,
*Secretary-Treasurer*



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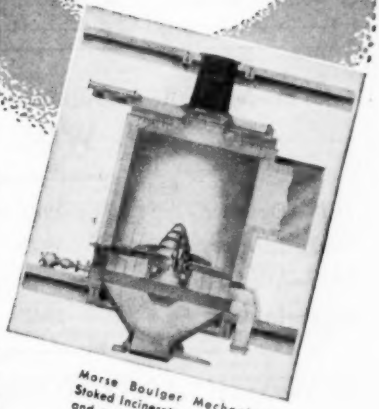

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**Running-Time Recorder**—A new bulletin (OP1504) describes application of new Series 500 Running-Time Recorders to various process units.—The Bristol Co., Waterbury 20, Conn.

(*Continued on page 74a*)

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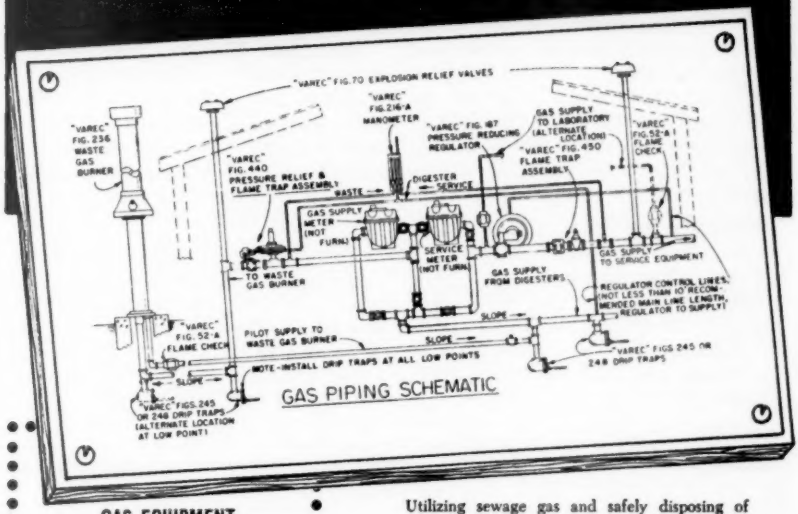
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 87 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES (NOT LESS THAN 10' RECOM. MENDED MAIN LINE LENGTH, REGULATOR TO SUPPLY)
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
SLOPE
SLOPE
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
"VAREC" FIGS. 245 OR 248 DRIP TRAPS
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
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b. **FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 450

c. **FLAME CHECK**
"VAREC" Fig. No. 52A

d. **EXPLOSION RELIEF VALVES**
"VAREC" Fig. No. 70-1

e. **WASTE GAS BURNER**
"VAREC" Fig. No. 236

f. **DRIP TRAPS**
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

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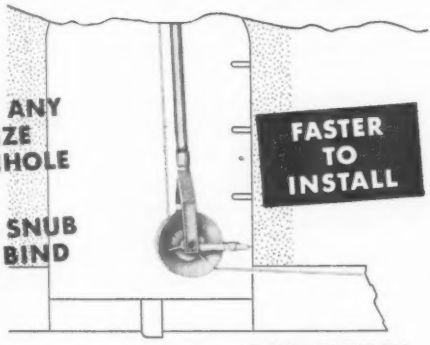


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